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Body height in adult women and men in Geneva: Temporal trends, association with general health status, and height loss after age 50

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Abstract

Objective: On the one hand, trends in average height in adulthood mirror changes in living standard and health status of a population and its subgroups; on the other hand, body height in general, as well as the loss of height in older age in particular, are associated in different ways with outcomes for health. For these aspects, there is hardly any information for Switzerland based on representative and measured body height data.

Design: Repeated cross-sectional survey study.

Setting: Fully anonymized data from the representative and population-based Geneva Bus Santé Study between 2005 and 2017 were analyzed.

Methods: Data from N=8,686 study participants were used in the trend analysis. Height was measured and socio-demographic information and self-rated health was collected via questionnaires. Follow-up (mean: 7.1 years) measurements from N=2,112 participants were available to assess height loss after age 50.

Results: Among men and women, higher socioeconomic status was associated with taller average height. The flattening of the increase in height from the 1970s birth years appears to begin earlier in the subgroup with the highest level of education. The tallest average height was measured for men and women from Central and Northern Europe, and the shortest for South America and Asia. The likelihood that participants rated their health as "very good" increased with greater body height. The follow-up data show that women lost significantly more height after age 50 than men.

Conclusions: The association of body height and health status is currently understudied. Monitoring changes in average body height may indicate disparities in different subgroups of populations. Too little attention is paid to the importance of body height for health in the public health domain.

Word count: 3963

Article summary

Strengths:

- Repeated representative and population-based cross-sectional study
- Measured body height using standardized protocols

Limitations:

- A healthy participant bias and remaining confounding cannot be excluded
- The number of follow-up measurements after age 50 is limited at the moment

1. Introduction

Adult height is the result of a dynamic and complex additive growth process [1,2]. The determinants include both genetics (responsible for up to 80%) and environmental factors (nutrition, disease environment, physical workload, socioeconomic background, etc.) [3]. Their interactions result in phenotypic variation [4]. Height is also connected with health in various ways, as it acts both as an indicator and as a possible determinant of health [5].

The average height at various ages mirrors environmental conditions, such as nutrition, health and socioeconomic status [6]. For past and modern societies, changes in mean height or height distribution over decades and centuries reflect changes in health and well-being [7–9]. Improvements in access to food, dietary diversification, sanitation, water and living standards as well as decreases in exposure to diseases were found to be associated with the secular increase in height observed in the 19th and 20th centuries in Switzerland as well as in other European countries [5,10,11]. As height may be considered a proxy of health status, monitoring growth and height based on ongoing systematic public health surveillance can help identifying and tracking inequalities between population subgroups, thereby opening up fields for interventions [12–15].

Over the past 20-40 birth years, this steady secular increase in average height has plateaued or at least slowed [16]. Reasons for this development, despite the further growing standard of living, is not fully understood. Reaching the genetic limits [16], decreasing the amounts of proteins consumed and decreasing total energy intake [17] as well as increasing social inequality (which could prevent socially disadvantaged groups from realizing their hereditary growth potential) are potential explanations. There is a research gap regarding whether this plateauing takes place in all subpopulations of wealthier populations. One of the few studies assessing this topic investigated the connection between height and socio-economic background characteristics in Moroccan and Turkish children living in the Netherlands [18].

On the other hand, height is also a co-determinant of future health and well-being. Research on the association between adult height and mortality of specific diseases is generally heterogeneous [5,19]. Adult height displays both positive and negative associations with different disease-specific outcomes [19]. Overall, however, there is a negative relationship between all-cause mortality and height, even if it is not yet clear whether this effect is independent from other factors related to height (i.e., socio-economic factors) [5,11]. Therefore, height might influence not only physical health but also subjective well-being [5,20]. In addition, most people lose body height after age 40-50, and this adult height loss is in turn associated with negative health consequences later in life (bone health, cardiovascular health, general health status, etc.) [21–26].

Historical and recent developments in height in Switzerland have been described based on conscript data and through passport applications, maternity hospitals and prisoner data sources [16]. The literature shows that the secular increase since the end of the 19th century has been slowing down. However, it has not yet been determined whether this is the case for subpopulations defined by socioeconomic background, migration background, education level, etc. Previous studies were performed on Genevan conscripts [27] and discussed differences in height in terms of environmental and economic determinants [28]. However, as these studies were done on conscript data only, they represent merely a part of the population, namely, young Swiss men. These studies do not include women, nor do they include adults with migration backgrounds. Furthermore, there are few longer-running population-based health studies in Switzerland that include measured body heights.

In this study, we used data from a unique representative health survey of the Geneva general population and aimed to answer the following questions. First, using this large dataset, we wanted to investigate whether the slowdown in height increase in recent decades has affected all subgroups (education level and migration background) of the Geneva population. Second, we investigated whether height was associated with self-assessed health status. Third, in a small subsample, we were interested in whether and to what extent the Geneva population was affected by height loss.

2. Material and methods

For this paper, individual data from the *Bus Santé* study were used. *Bus Santé* is a population-based study conducted in Geneva, Switzerland, which was launched in 1993 and has been running ever since. Details on the study and the protocols are outlined in detail elsewhere [29]. Every year, a new representative sample of 500 men and 500 women is selected from the Geneva population using residential lists provided by the local government. Until 2009, a study population aged 34-75 was investigated; from 2010 on, the study age range was extended to 20-74 years. To be proportional to the corresponding population distributions, stratified random sampling in age and sex strata was performed. The study team reached out to individuals by mail, and if they were not responsive, they were called seven times. Then, two letters were sent. If they still could not be reached, they were replaced by another individual. However, if they refused to participate, they were not replaced. The 1999–2009 mean participation rate was 60% (range: 55%–65%).

Each participant received several self-administered, standardized questionnaires covering the risk factors for major lifestyle chronic diseases, sociodemographic characteristics, educational and occupational histories and reproductive history for women. Each participant brought their completed questionnaires to one of the two study centres located in hospitals and one mobile examination bus visiting three parts of the Canton of Geneva, where the questionnaires were checked for correct completion by trained interviewers [30]. Then, a comprehensive health assessment was performed, which also included several measurements (an overview is presented elsewhere [31]). Height was also measured in a temperature-controlled room in the standing position using a medical gauge (precision 1 cm) [32].

Variables in this study

With reference to our research questions (presented in the introduction), we worked with the following subdata sets from the *Bus Santé* study:

For most of our analyses, we focused on the examination years since 2005, when education level was available from the questionnaires. Measured and continuous body height (in cm) was the dependent variable for the time trend analysis. In terms of cofactors with relevance for height research, we used the nationality of the participants' parents to classify their migration background into six large groups: Central European (which also includes people with a Western European migration background), Southern European, Eastern European (which also includes people with a Southeast European migration background), South American, African and Asian. For all other migration backgrounds, the sample size was too small, so these migration backgrounds were combined into “Other”. Both parents should have had the same migration background; if this was not the case, they were also classified under “Other”. To simplify the outputs, we only showed those where both parents had the same migration background and do not show the “Other” category. Following previous publications using *Bus Santé* data [33], education level was categorized into two groups, namely, in primary/secondary education (no degree or with a compulsory school degree, completed high school or apprenticeship) and in tertiary education (higher degree with a high school diploma). Additionally, information about the number of siblings was available (regarding resource allocation in childhood, this could also play a role in body growth, as has been shown for historical societies [34]). The number of siblings was divided into four groups (“none”, “one”, “two”, “more”). Additionally, the years of birth were grouped in 10-year increments (1933-1942, 1943-1952, 1953-1962, 1963-1972, 1973-1982, 1983-1993).

The data also included the ZIP code of the residential address of the participants, which we used for our analysis by city neighbourhood within Geneva. To compare the average height in a given ZIP code with the area-based socioeconomic position of the ZIP code, we used the mean Swiss-SEP 2.0 (area-based index of socioeconomic position in Switzerland) per ZIP code. Swiss-SEP 2.0 indicates the average socioeconomic situation in a postal code and was developed and made available by the Institute for Social and Preventive Medicine at the University of Bern [35]. Additionally, published average heights of Swiss conscripts (18-22-year-old Swiss men, >90% coverage due to mandatory conscription, examination years 2010-2017) were used for comparison on the ZIP code level.

For our analysis of the association between height and health status, self-rated health status was the dependent variable. Answers to the questionnaire were grouped into four categories: “Very good”, “good”, “fair” and “bad/very bad”. For our analysis of adult height loss and to achieve the largest possible follow-up sample size, we also considered the earlier examination years from 1999-2005. For this smaller follow-up sample, the first examination took place in the years 1995-2003, and the follow-up examination was in 2005-2008.

We used the STROBE cross sectional reporting guidelines [36].

Ethics

For the entire *Bus Santé* study, all participants provided written informed consent, and *Bus Santé* was approved by the local institutional review board (Commission Cantonale d'Ethique de la Recherche de Genève; IRB00003116). Because the study owners provided only anonymized data to the study team for this article, no additional ethics approval was required.

Patient and Public Involvement

Patients or the public were not involved in the design, or recruitment, or conduct, or reporting, or dissemination plans of our research.

Statistical methods

All analyses were carried out separately for men and women. The unadjusted association between average height and Swiss-SEP of ZIP codes was displayed via maps and scatterplots.

To model trends and potentially nonlinear effects of cofactors, we used general additive models (GAMs). GAMs are an extension of generalized linear models obtained by allowing not only linear associations but also general smooth terms [37]. In our models, we used a smooth term for the independent variable year of birth. The fully adjusted model for the survey years 2005-2017 contained the following additional linear terms: year of survey, education, number of siblings, migration background of the mother and migration background of the father. In the next step, we stratified this analysis by migration background and educational level. In a sensitivity analysis, the 2005-2017 GAM was run unadjusted (only containing the smooth term year of birth) and compared to an equivalent model based on the full range of survey years 1995–2017. Furthermore, we also compared the men's results with the published values of mean body heights of the conscripts (young Swiss men, 90% coverage).

To assess the association between height and self-rated health status, ordered logistic regression was used to predict probabilities of self-rated health status in relation to body height. The predictions of the probabilities were shown for mean age, primary/secondary education and migration background in Central Europe.

To examine the influence of each independent variable on body height and self-rated health status in the GAM and the ordered logistic regressions, we removed one independent variable from the model at a time and calculated the AIC (Akaike's information criterion). Next, the difference between the AIC for the full Model M and the model with omission of an independent variable k was calculated (i.e., $\Delta AICk=AICk-AIC_M$). The larger ΔAICk is, the more important the variable is in the model.

To explore height loss, follow-up measurements of height were available in a small subsample of participants. For these participants, the first examination took place in 1995-2003, and the follow-up examination was in 2005-2008. We only included participants who were >=50 years old at the first examination and whose second examination was at least five years later. The reason for this approach was that height loss does not occur until the second half of life, and requires a certain follow-up duration for differences to manifest. The height loss was calculated as the delta height between the two examinations and standardized per year of follow-up. A one-sample two-sided t test with a 95% confidence interval was used to verify whether the height loss per 1-year follow-up differed from zero. The results are displayed per age group using boxplots.

3. Results

The initial sample 2005-2017 included n=10,585 participants. The inclusion/exclusion procedure is documented in Supplementary Figure S1. We excluded participants born before 1932 (n=17), with a height <140 cm (n=24), >210 (n=8), with missing data regarding height (n=282), parent's place of birth (n=1,442), education level (n=125) or number of siblings (n=18). The sample that we used for the trend analysis included n=8,686 participants (82.0% of the initial data), of which 51.7% were women. Female participants in this sample were, on average, 166.2 cm (SD 6.5) tall, and male participants were 179.2 cm (SD 6.5). The frequency distributions of the categorical variables are displayed in Table 1. Most of the participants were born between 1943 and 1982. The mean ages of males (49.3 years, SD 13.3) and females (49.1 years, SD 13.1) were similar. Women were slightly less likely to report secondary or tertiary education (43.2% in women vs. 47.0% in men). The majority of the participants (51.0%) reported their nationality as Central Europe (including Switzerland). The second most frequent region was Southern Europe (20.8%), and other regions, such as Africa, Asia or South America, were less frequent (<6%). The majority of the participants had one or two siblings, and only 11.3% reported having no siblings.

Figure 1 shows the modelled trend of average height for men and women across birth years. When adjusting the model for all available cofactors which are relevant for body height, the level of average height is generally slightly higher. Both males and females grew taller over time. The adjusted trends show a slowdown in the increase in height from the birth years from the 1970s. In men, the most recent birth years again show a slight increase. A sensitivity analysis (Supplementary Figure S2) shows that the unadjusted trends from the 2005-2017 sample match the trends from the entire 1992-2017 sample well and, for males, they also match the averages from military conscription (young Swiss men from Geneva, 90% representativeness). Considering the cofactors in the models, the examination of Δ AIC shows that for men and women, migration background was the most important factor in explaining body height, followed by year of birth. For both sexes, education ranked third, and the number of siblings ranked fourth (Supplementary Table 1). The year of the survey was unimportant. When displaying the average Swiss-SEP of ZIP codes (as a proxy for area-based socioeconomic position) in the city of Geneva against the average height of participants living in those ZIP codes, we see a positive association. In higher Swiss-SEP ZIP Codes, men and women were taller on average (the same also accounts for conscripts, see Supplementary Figure S3).

A closer inspection of the trends by education level in Figure 2 (the models are again adjusted for the other co-factors) shows that people in the tertiary education group were taller than people in the primary/secondary education group. Moreover, the tertiary education group plateaued from 1963-1972, whereas people in the primary/secondary education group continued to grow taller. Among women, the difference between the tertiary and primary/secondary educational groups also narrows by birth years 1998-1993. Supplementary Figure S4 illustrates the differences in height trends according to migration background. Men and women from Central Europe (including Switzerland) and Eastern Europe were the tallest, whereas people from South America and Asia were the shortest. For people with Central European migration backgrounds, a height plateau was reached starting with birth years 1963-1972. For people with Southern European migration backgrounds, women's body height has stagnated since the 1963-1972 birth years, whereas men continue to grow taller.

To assess the association between height and self-rated health status, we had to exclude another n=1,749 participants for whom this information was missing in the dataset. Figure 3 illustrates the remaining data (n=6,937, 65.5% of the initial dataset). The probability of men and women rating their health status as "very good" increased with increasing body height (these models were again adjusted for the other co-factors. The results of the ΔAIC examination (Supplementary Table 1) revealed that body height was an important factor in describing self-rated health status. In women, body height was even more important than "age" in describing self-rated health status.

For a subsample of n=2,112 participants, follow-up measurements of height were available to estimate the height loss per 1-year follow-up. The mean delta in years between the two measurements was 7.1 years (SD 1.8) (the distribution of height loss are presented as histograms in Supplementary Figure S5). Overall, men lost -0.11 cm per year of follow-up (95% CI -0.12 to -0.10, p<0.001), and women lost -0.17 cm (95% CI -0.18 to 0.15, p<0.001). Thus, women lost on average -0.06 cm (95% CI -0.07 to -0.04 cm, p<0.001) more than men. Figure 4 shows that the older the participant was at the first examination, the greater the height loss was when re-examined.

4. Discussion

Measured and representative information on the height of adult men and women is rarely available, especially in regard to the question of whether within European countries, growth of all subgroups of a population have slowed down or become steadily taller. Here, we analysed body height in a unique population-based and sufficiently large dataset 2005-2017 from the Swiss city of Geneva. We found that both men and women have become significantly taller across birth years in the 20th century but that this increase has slowed down since the 1970 birth years. Migration background and year of birth were the most important explanatory factors for height, followed by education level. We also found a positive association between average height and area-based SEP across ZIP codes within the city. Men and women with migration backgrounds in Central and Eastern Europe were the tallest, and participants with migration backgrounds in South America and Asia were the shortest. In terms of time trends and slowdown of increase, we see some differences by subgroup (education level and migration background). Furthermore, taller height was an important cofactor in explaining better self-rated health status. In a follow-up sample, we showed that participants over the age of 50 lost height over time.

In this study, we showed that even in an urban population, the slowdown in the increase in body height since the 1970s birth cohorts, which has already been shown for Switzerland as a whole, is confirmed. The Geneva data we presented here are reliable in that they are based on objectively measured heights in a representative and relatively large dataset (which was less the case in the mentioned Switzerland-wide study) [38]. We showed that there are differences in recent height trends between education levels and migration groups in Geneva. For example, we observed that on average, taller people with tertiary education stopped growing taller in height earlier than people with lower education levels. In the youngest birth cohorts included in the *Bus Santé* study, we can even observe a closing of this height gap between the education levels. Whether this continues or whether the youngest study participants have simply not yet completed their education will become clear in the coming years. That there are differences in these rather recent height trends according to the subgroups of a population has already been shown for the Netherlands, where the secular height increase in Dutch children has come to a halt, whereas the trend continued in Turkish and Moroccan children living in the Netherlands [18].

The differences in average body height by ZIP code within the city of Geneva and the spatial correspondence with higher and lower socioeconomic neighbourhoods that we have shown are consistent with other studies that have examined other health-related aspects in the *Bus Santé* study on a small-scale basis: Geneva neighbourhoods where the average height was taller also tended to be neighbourhoods where the obesity rate or sweetened beverage (SB) intake was lower [39,40]. This is an indication that the social topography within a city is an important cofactor in studies of this kind. For Switzerland as a whole, ZIP code clusters of taller and shorter people had already been documented on the basis of conscripts in earlier studies [41]. The results presented here add to this literature by showing that this concept is also important within cities. For now, it must remain an open question to what extent clusters of certain cultural, socioeconomic, and migration-related factors in certain neighbourhoods are the drivers behind these patterns.

Height loss in adulthood has not been studied in Switzerland for 70 years [42]. The present study is the first to revisit this topic for Switzerland and to provide an indication that this health-related aspect for elderly people should be studied more broadly. The descriptive results presented here for Geneva are consistent with previous literature in that height loss increased with increasing age and that women were generally more affected by height loss than men [21,22,24–26,43]. The latter phenomenon could be influenced by menopause (possibly also hormonal influences) or by the generally higher risk in women of poorer bone health later in life [43]. Among the reasons for height loss are weakening of muscle groups, postural changes, disc degeneration, frailty, joint space narrowing, spinal deformities, and kyphosis [43]. If further studies confirm the relevance of height loss as a factor for later health [25,26], then height measurements and assessment of height loss should be part of the regular examinations from the age of 40 or 50 to monitor health status in general, especially in the case of severe height loss, and more often among women than men.

The strengths of this study clearly lie in the underlying, unique data material. There are few rolling representative population-based studies of this sample size with precisely measured body heights (including partial follow-up measurements). Another advantage is that the migration background was included more precisely than usual via the parents' place of birth. In terms of limitations, the following points should be noted. First, information on the important variable education level has only been collected since 2005. However, the remaining study size was still large enough to answer the research questions. Second, population-based health studies have tended to struggle with declining participation rates in recent years. This is only partly the case with *Bus Santé*, as much time and effort have been invested by the study operators in participant recruitment. It cannot be ruled out that *Bus Santé*, like other similar studies, also exhibits a healthy participant bias in which unhealthier people may be more likely not to participate. Third, the association between body height and health status examined here was limited. Future studies could go into more depth here by including further measurements from the broad measurement battery performed in the *Bus Santé* study. It is clear that the self-assessed general health variable used here is subjective and can only provide a first indication. Fourth, the height loss follow-up sample studied here was still too small. In the future course of the *Bus Santé* study, it will be interesting to include further follow-up measurements as well as link height loss with health outcomes later in life. Fifth, in observational study causality cannot determined. It is also possible that, despite the use of adjusted models, certain results were still influenced by remaining confounding factors.

Conclusion

In research on body height, current trends and associations with health have not been sufficiently considered. For example, trend monitoring by subgroups within certain populations reveals that not all subgroups seem to slowdown in getting taller, and there may be differences by education level and migration background. This also points in the direction of the relevance of social inequality in this context, which can also be mirrored and monitored to some extent by such height trends. Mean body height seems to be a good measure of deficiency (as long as the genetic growth potential is not yet exhausted) but less abundant (than mean body height plateaus). Moreover, the effects of body height on health are still considered too little in the public health field. This is especially true for height loss in the second half of life, where better data are needed.

Author statements

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Ethics approval: For the entire *Bus Santé* study, all participants provided written informed consent, and *Bus Santé* was approved by the local institutional review board (Commission Cantonale d'Ethique de la Recherche de Genève; IRB00003116). Because the study owners provided only anonymized data to the study team for this article, no additional ethics approval was required.

Data sharing statement: Consent has not been obtained to share the data publicly. However, data may be accessed on contacting the study team (https://www.hug.ch/medecine-premier-recours/bus-sante). The statistical analysis scripts can be obtained by contacting the corresponding author.

Patient consent for publication: Not required.

Bibliography

1 Wells JC. Worldwide variability in growth and its association with health: Incorporating body composition, developmental plasticity, and intergenerational effects. *Am J Hum Biol* 2017;**2017-01–22**.

2 Tanner JM. *Foetus into Man. Physical Growth from Conception to Maturity*. 2nd ed. Cambridge, Mass.: : Harvard University Press 1990.

3 Bogin B. *Patterns of human growth*. 2nd ed. Cambridge: : Cambridge University Press 1999.

4 Floud R, Fogel R, Harris B, *et al. The changing body: health, nutrition, and human development in the Western world since 1700*. Cambridge: : Cambridge Univ. Press 2011.

5 Perkins JM, Subramanian S V., Smith GD, *et al.* Adult height, nutrition, and population health. *Nutr Rev* 2016;**74**:149–65. doi:10.1093/nutrit/nuv105

6 Kues AB. Taller - Healthier - more equal? The biological standard of living in Switzerland in the second half of the 20th century. *Econ Hum Biol* 2010;**8**:67–79. doi:10.1016/j.ehb.2009.09.002

7 Cole TJ. The secular trend in human physical growth: a biological view. *Econ Hum Biol* 2003;**1**:161–8. doi:S1570677X02000333 [pii]10.1016/S1570-677X(02)00033-3

8 Gausman J, Meija Guevara I, Subramanian S V., *et al.* Distributional change of women's adult height in low- and middle-income countries over the past half century: An observational study using cross-sectional survey data. *PLOS Med* 2018;**15**:e1002568.

9 Komlos J. Anthropometric history: an overview of a quarter century of research. *Anthr Anz* 2009;**67**:341–56.

10 Rohrmann S, Haile SR, Staub K, *et al.* Body height and mortality - mortality follow-up of four Swiss surveys. *Prev Med (Baltim)* Published Online First: 2017. doi:10.1016/j.ypmed.2017.05.023

11 Gausman J, Meija Guevara I, Subramanian S V., *et al.* Distributional change of women's adult height in low- and middle-income countries over the past half century: An observational study using cross-sectional survey data. *PLOS Med* 2018;**15**:e1002568. doi:10.1371/journal.pmed.1002568

12 Groseclose SL, Buckeridge DL. Public Health Surveillance Systems: Recent Advances in Their Use and Evaluation. *Annu Rev Public Health* 2017;**38**:57–79. doi:10.1146/annurev-publhealth-031816-044348

13 German RR, Lee LM, Horan JM, *et al.* Updated guidelines for evaluating public health surveillance systems: recommendations from the Guidelines Working Group. *Recomm reports Morb Mortal Wkly Rep* 2001;**50**:1–35.http://www.ncbi.nlm.nih.gov/pubmed/18634202 (accessed 4 Jan 2017).

14 Grantham-McGregor S, Powell C, Walker S. Nutritional supplements, stunting, and child development. *Lancet* 1989;**2**:809–10.http://www.ncbi.nlm.nih.gov/pubmed/2571055

15 Tanner JM. The potential of auxological data for monitoring economic and social well-being. *Soc Sci Hist* 1982;**6**:571–81.

16 Vinci L, Floris J, Koepke N, *et al.* Have Swiss adult males and females stopped growing taller? Evidence from the population-based nutrition survey menuCH, 2014/2015. *Econ Hum Biol*

2019;**33**:201–10. doi:10.1016/J.EHB.2019.03.009

17 Abreu D, Cardoso I, Gaspoz JM, *et al.* Trends in dietary intake in Switzerland, 1999 to 2009. *Public Health Nutr* Published Online First: 2014. doi:10.1017/S1368980013000207

18 Schönbeck Y, van Dommelen P, HiraSing RA, *et al.* Trend in Height of Turkish and Moroccan Children Living in The Netherlands. *PLoS One* 2015;**10**:e0124686. doi:10.1371/journal.pone.0124686

19 Wormser D, Di Angelantonio E, Kaptoge S, *et al.* Adult height and the risk of cause-specific death and vascular morbidity in 1 million people: Individual participant meta-analysis. *Int J Epidemiol* Published Online First: 2012. doi:10.1093/ije/dys086

20 Coste J, Pouchot J, Carel JC. Height and health-related quality of life: A nationwide population study. *J Clin Endocrinol Metab* Published Online First: 2012. doi:10.1210/jc.2012-1543

21 Hannan MT, Broe KE, Cupples LA, *et al.* Height loss predicts subsequent hip fracture in men and women of the Framingham Study. *J Bone Miner Res* 2012;**27**:146–52. doi:10.1002/jbmr.557

22 Sorkin JD, Muller DC, Andres R. Longitudinal Change in Height of Men and Women: Implications for Interpretation of the Body Mass Index: The Baltimore Longitudinal Study of Aging. *Am J Epidemiol* 1999;**150**:969–77. doi:10.1093/oxfordjournals.aje.a010106

23 Moayyeri A, Kaptoge S, Luben RN, *et al.* Estimation of absolute fracture risk among middle-aged and older men and women: the EPIC-Norfolk population cohort study. *Eur J Epidemiol* 2009;**24**:259–66. doi:10.1007/s10654-009-9337-8

24 Pluskiewicz W, Adamczyk P, Drozdzowska B. The significance of height loss in postmenopausal women. The results from GO Study. *Int J Clin Pract* 2021;**75**. doi:10.1111/ijcp.14009

25 Masunari N, Fujiwara S, Nakata Y, *et al.* Historical height loss, vertebral deformity, and health-related quality of life in Hiroshima cohort study. *Osteoporos Int* 2007;**18**:1493–9. doi:10.1007/s00198-007-0392-2

26 Wannamethee SG. Height Loss in Older Men. *Arch Intern Med* 2006;**166**:2546. doi:10.1001/archinte.166.22.2546

27 Staub K, Rühli FJ. 'From growth in height to growth in breadth': the changing body shape of Swiss conscripts since the late 19th century and possible endocrine explanations. *Gen Comp Endocrinol* 2013;**188**:9–15. doi:10.1016/j.ygcen.2013.03.028

28 Staub K, Rühli FJ, Bogin B, *et al.* Edouard Mallet's early and almost forgotten study of the average height of Genevan conscripts in 1835. *Econ Hum Biol* Published Online First: 2011. doi:10.1016/j.ehb.2011.03.001

29 Sandoval JL, Leão T, Theler J-M, *et al.* Alcohol control policies and socioeconomic inequalities in hazardous alcohol consumption: a 22-year cross-sectional study in a Swiss urban population. *BMJ Open* 2019;**9**:e028971. doi:10.1136/bmjopen-2019-028971

30 Dumont S, Marques-Vidal P, Favrod-Coune T, *et al.* Alcohol policy changes and 22-year trends in individual alcohol consumption in a Swiss adult population: A 1993-2014 cross-sectional population-based study. BMJ Open. 2017. doi:10.1136/bmjopen-2016-014828

31 Schneid Schuh D, Guessous I, Gaspoz J-M, *et al.* Twenty-four-year trends and determinants of change in compliance with Swiss dietary guidelines. *Eur J Clin Nutr* 2019;**73**:859–68. doi:10.1038/s41430-018-0273-0

32 Guessous I, Bochud M, Theler JM, *et al.* 1999-2009 trends in prevalence, unawareness, treatment and control of hypertension in Geneva, Switzerland. *PLoS One* Published Online First: 2012. doi:10.1371/journal.pone.0039877

33 Guessous I, Bochud M, Theler JM, *et al.* 1999-2009 Trends in prevalence, unawareness, treatment and control of hypertension in Geneva, Switzerland. *PLoS One* 2012;**7**:e39877. doi:10.1371/journal.pone.0039877

34 Mazzoni S, Breschi M, Manfredini M, *et al.* The relationship between family characteristics and height in Sardinia at the turn of the twentieth century. *Hist Fam* 2017;**22**:291–309. doi:10.1080/1081602X.2016.1230509

35 Panczak R, Galobardes B, Voorpostel M, *et al.* A Swiss neighbourhood index of socioeconomic position: development and association with mortality. *J Epidemiol Community Health* 2012;**66**:1129–36. doi:10.1136/jech-2011-200699

36 von Elm E, Altman DG, Egger M, *et al.* The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *J Clin Epidemiol* 2008;**61**:344–9. doi:10.1016/j.jclinepi.2007.11.008

37 Wood S. *Generalized additive models: an introduction with R*. 2nd ed. Boca Raton, Fla: : Chapman and Hall/CRC 2017.

38 Vinci L, Floris J, Koepke N, *et al.* Have Swiss adult males and females stopped growing taller? Evidence from the population-based nutrition survey menuCH, 2014/2015. *Econ Hum Biol* 2019;**33**. doi:10.1016/j.ehb.2019.03.009

39 Guessous I, Joost S, Jeannot E, *et al.* A comparison of the spatial dependence of body mass index among adults and children in a Swiss general population. *Nutr Diabetes* 2014;**4**:e111. doi:10.1038/nutd.2014.8

40 Joost S, De Ridder D, Marques-Vidal P, *et al.* Overlapping spatial clusters of sugar-sweetened beverage intake and body mass index in Geneva state, Switzerland. *Nutr Diabetes* 2019;**9**:35. doi:10.1038/s41387-019-0102-0

41 Panczak R, Moser A, Held L, *et al.* A tall order: Small area mapping and modelling of adult height among Swiss male conscripts. *Econ Hum Biol* 2017;**26**. doi:10.1016/j.ehb.2017.01.005

42 Büchi E. *Änderungen der Körpeform beim erwachsenen Menschen. Eine Untersuchung nach der Individual-Methode*. Horn, Wien: : Verlag Ferdinand Berger 1950.

43 Shimizu M, Kobayashi T, Chiba H, *et al.* Adult spinal deformity and its relationship with height loss: a 34-year longitudinal cohort study. *BMC Musculoskelet Disord* 2020;**21**:422. doi:10.1186/s12891-020-03464-2

Table 1: Descriptive statistics of the *Bus Santé* study population (examination years 2005-2017) after excluding missing values (see flow chart in Appendix Figure 1).

		Men (N=4199)	Women (N=4487)	Total (N=8686)
Year of birth	1933-1942	330 (7.9%)	330 (7.4%)	660 (7.6%)
	1943-1952	792 (18.9%)	837 (18.7%)	1629 (18.8%)
	1953-1962	910 (21.7%)	990 (22.1%)	1900 (21.9%)
	1963-1972	1211 (28.8%)	1233 (27.5%)	2444 (28.1%)
	1973-1982	565 (13.5%)	655 (14.6%)	1220 (14.0%)
	1983-1993	391 (9.3%)	442 (9.9%)	833 (9.6%)
Education	Primary/Secondary	2226 (53.0%)	2549 (56.8%)	4775 (55%)
	Tertiary	1973 (47.0%)	1938 (43.2%)	3911 (45%
Region	Africa	253 (6.0%)	223 (5.0%)	476 (5.5%)
	Asia	140 (3.3%)	166 (3.7%)	306 (3.5%)
	Central Europe	2089 (49.7%)	2344 (52.2%)	4433 (51.0%)
	Eastern Europe	137 (3.3%)	146 (3.3%)	283 (3.3%)
	Other	438 (10.4%)	499 (11.1%)	937 (10.8%)
	South America	143 (3.4%)	301 (6.7%)	444 (5.1%)
	Southern Europe	999 (23.8%)	808 (18.0%)	1807 (20.8%)
Siblings	None	459 (10.9%)	519 (11.6%)	978 (11.3%)
	One	1525 (36.3%)	1641 (36.6%)	3166 (36.4%)
	Two	934 (22.2%)	948 (21.1%)	1882 (21.7%)
	More	1281 (30.5%)	1379 (30.7%)	2660 (30.6%)

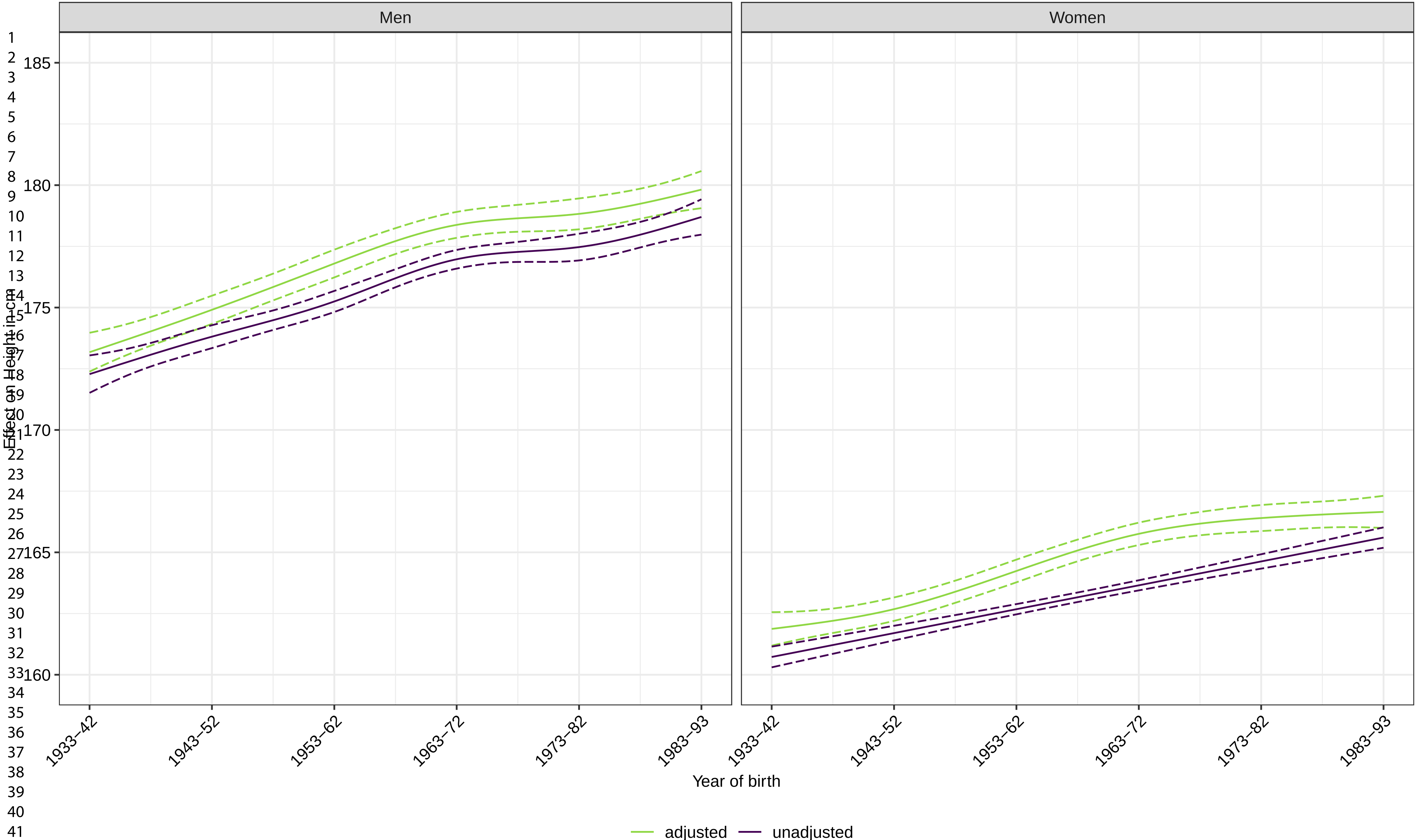
Figure legends

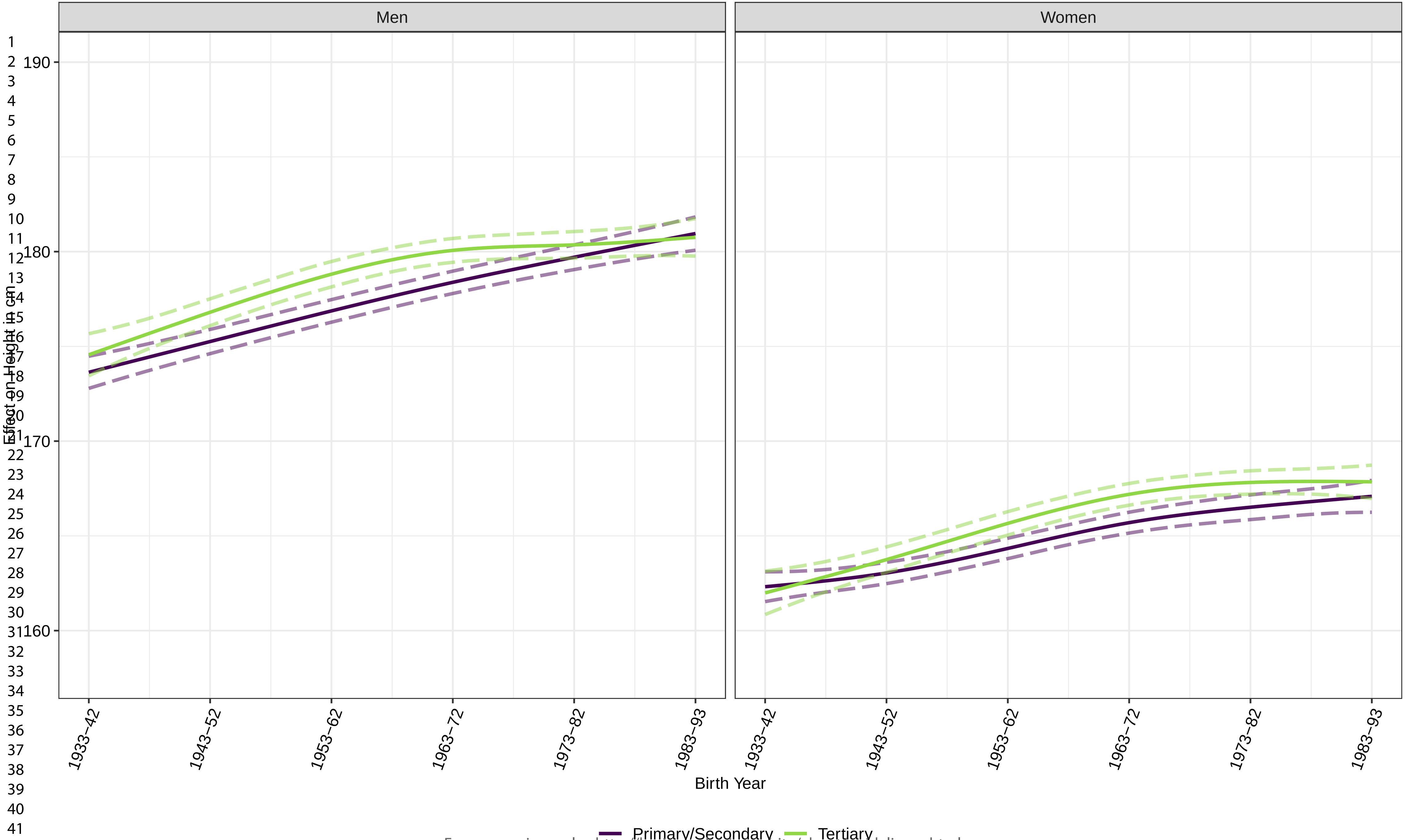
Figure 1: Modelled overall trends (unadjusted vs. adjusted) of average height across birth years among adult men (n=4199) and women (n=4487) in Geneva.

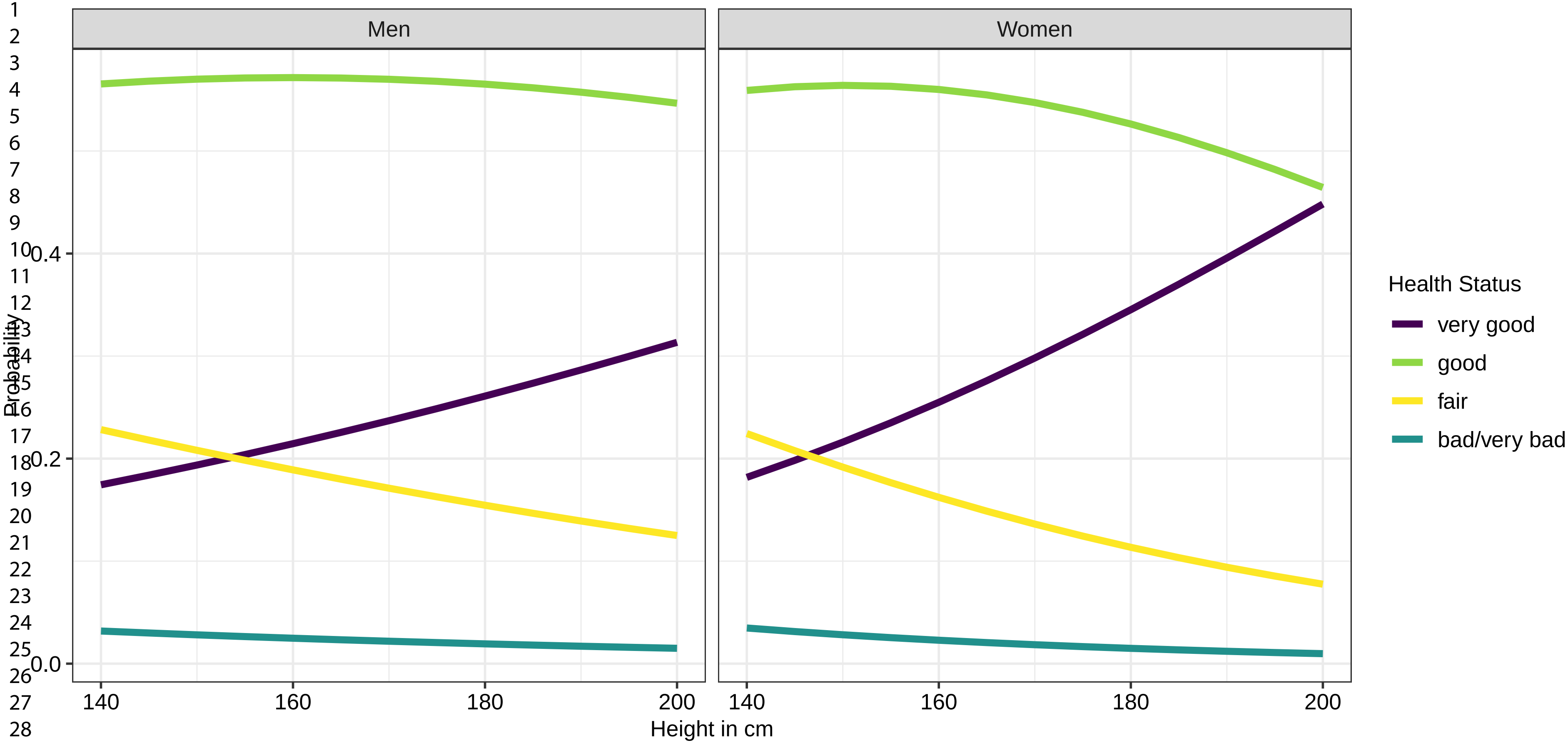
Figure 2: Modelled and adjusted trends for educational levels across years of birth among adult men and women in Geneva.

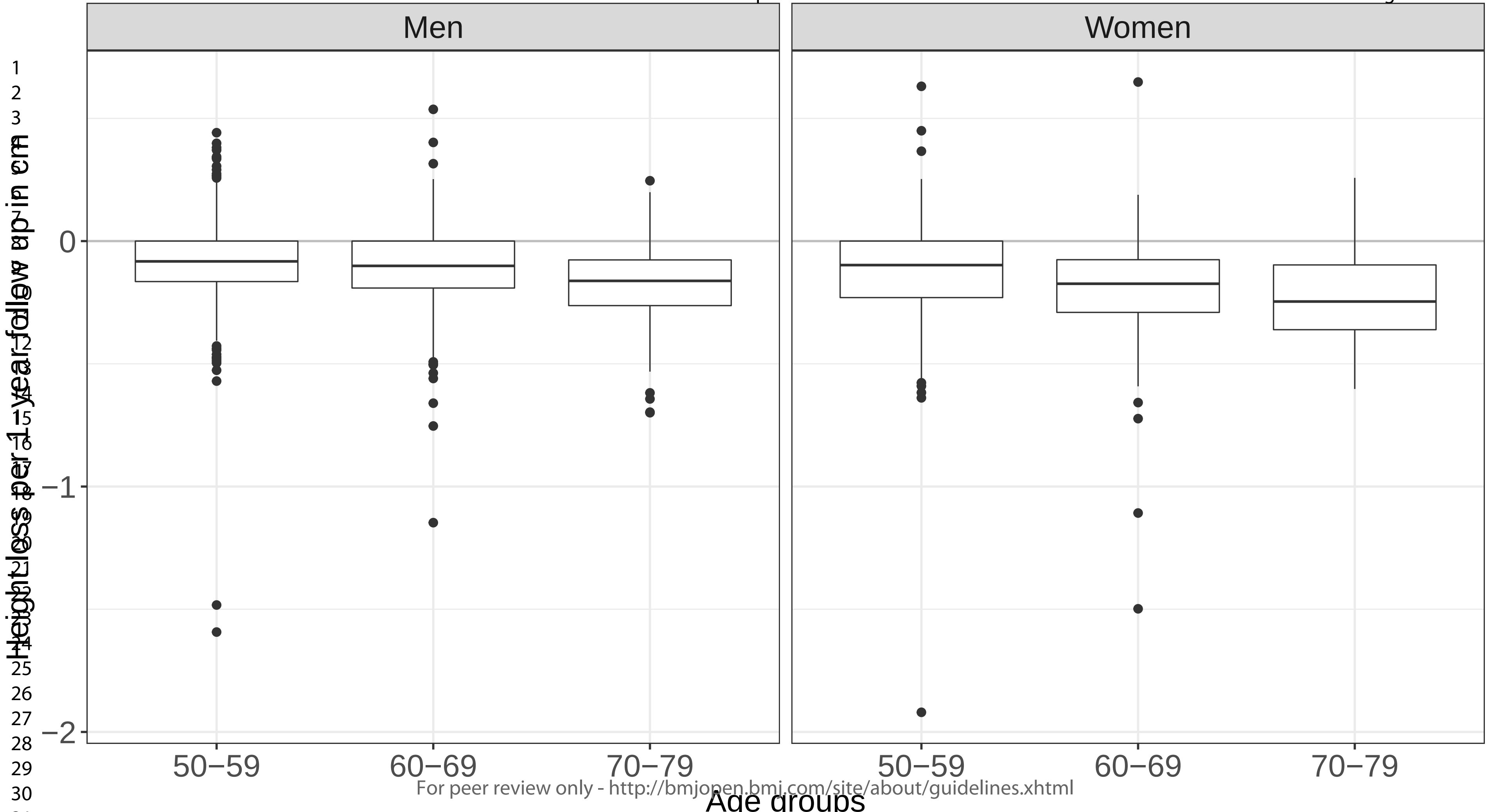
Figure 3: The probabilities of belonging to specific self-declared health status groups (lines) across the height spectrum (x-axis). The probabilities are shown for median age, primary/secondary education, Swiss nationality, and migration background in Central Europe.

Figure 4: Boxplots for height loss after age 50 years per year of follow-up across baseline age groups in a subsample of *Bus Santé* participants of both sexes.


Men
Women
Effect on Height in cm
185
180
175
170
165
160
1933–42
1943–52
1953–62
1963–72
1973–82
1983–93
Year of birth
adjusted
unadjusted


Men
Women
190
180
170
160
Effect on Height in cm
1933–42
1943–52
1953–62
1963–72
1973–82
1983–93
Birth Year
Primary/Secondary
Tertiary


Men
Women
Probability
0.4
0.2
0.0
140
160
180
200
Height in cm
Health Status
very good
good
fair
bad/very bad


Men
Women
0
−1
−2
50−59
60−69
70−79
50−59
60−69
70−79
Height loss per 1-year follow up in cm
Age groups

Supplementary Material

Supplementary Table S1: The results of the Δ AIC examination. The lower the Δ AIC the lower the importance of a given variable in a model.

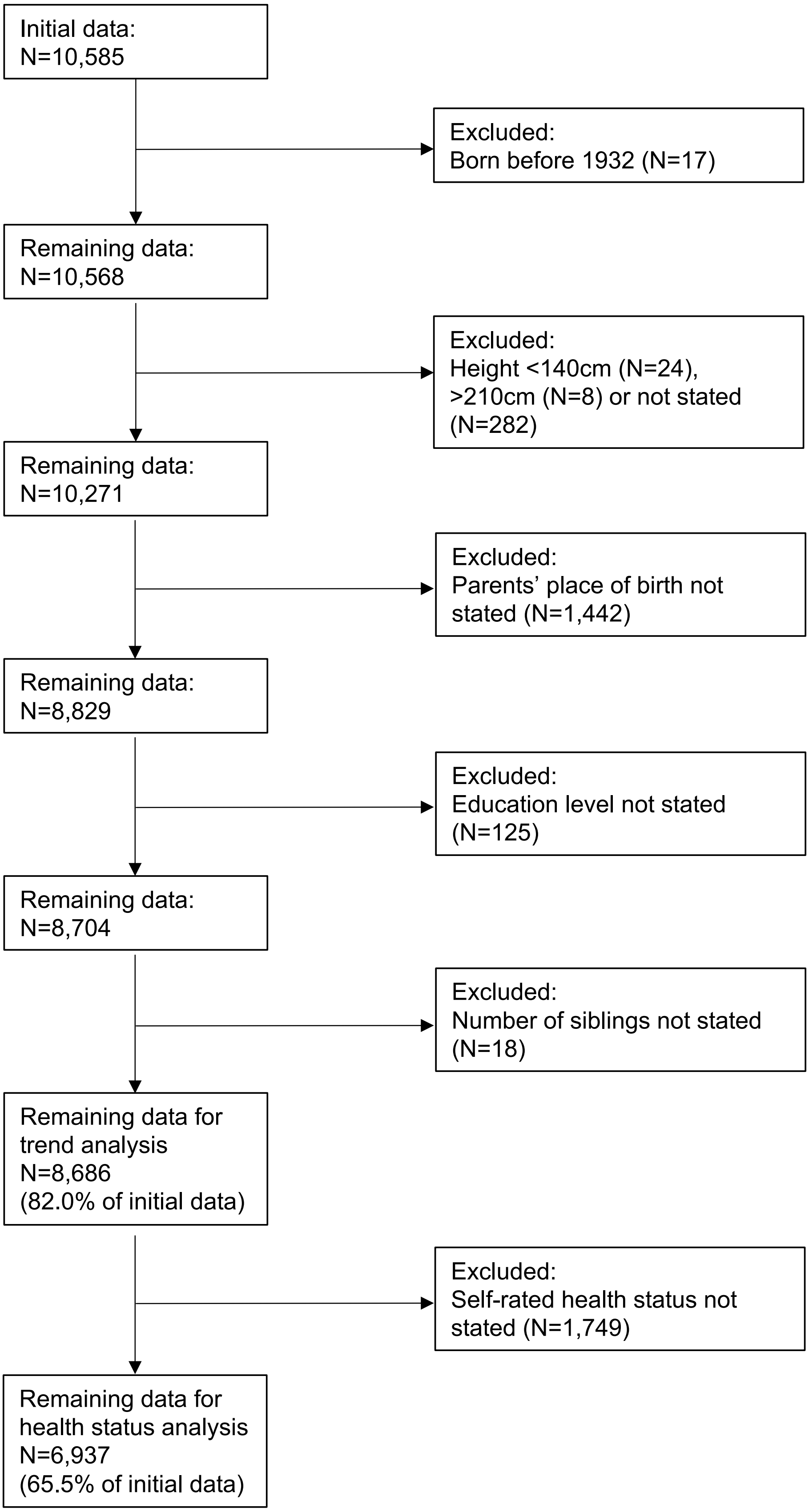
A) Models explaining height trends

Men		Women	
Parameter	**Δ AIC**	**Parameter**	**Δ AIC**
Migration	359.0	Migration	555.9
Birthyear	283.6	Birthyear	236.9
Education	91.6	Education	67.5
Sibling	31.6	Sibling	22.3
Examin. Year	0.7	Examin. Year	-1.9

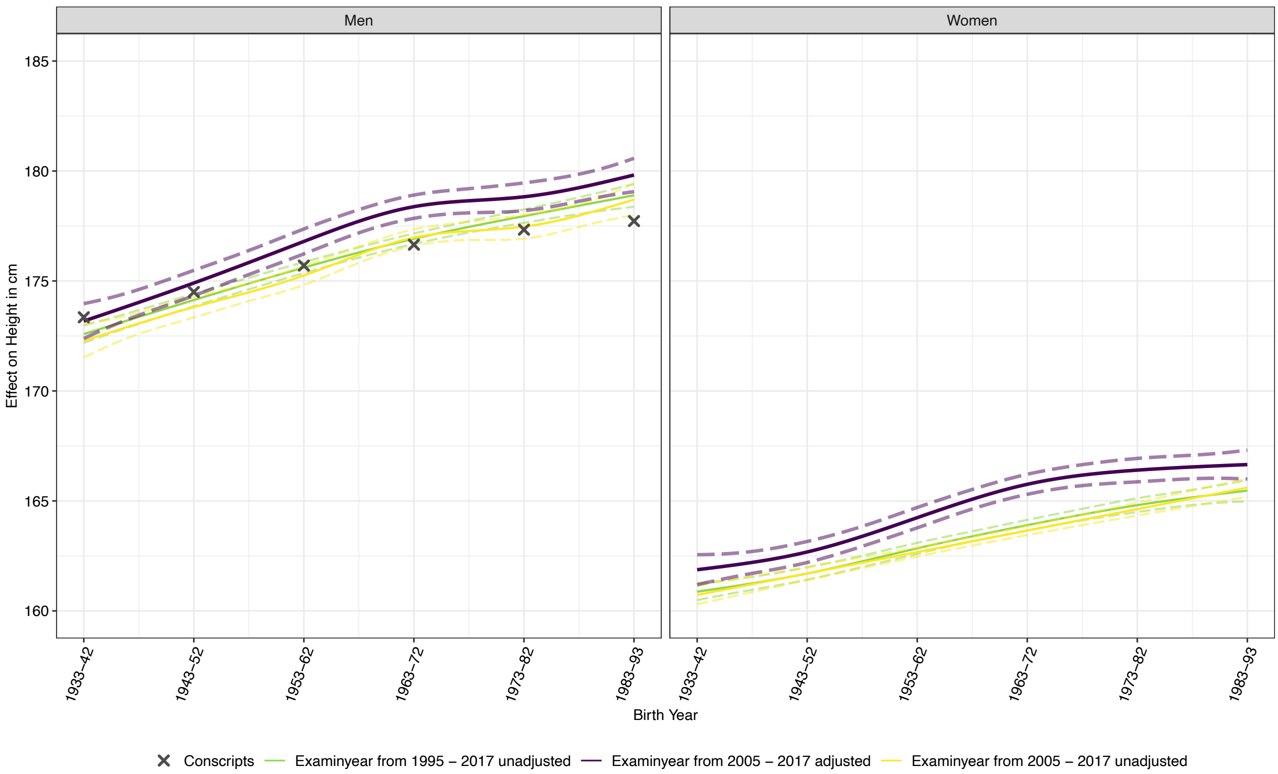
B) Models explaining health status

Men		Women	
Parameter	**Δ AIC**	**Parameter**	**Δ AIC**
Education	37.5	Migration	54.5
Age	35.5	Education	21.0
Migration	14.8	Height	14.8
Height	4.5	Age	7.9

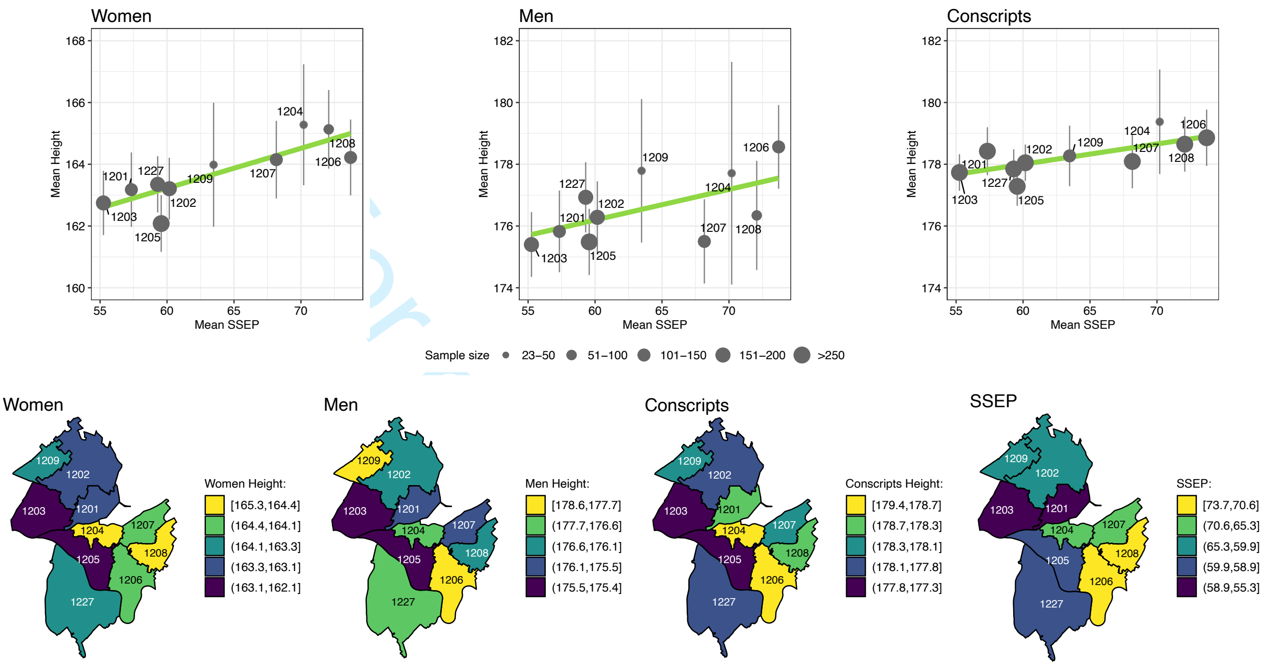
Supplementary Figure S1: Flow chart of data preparation.



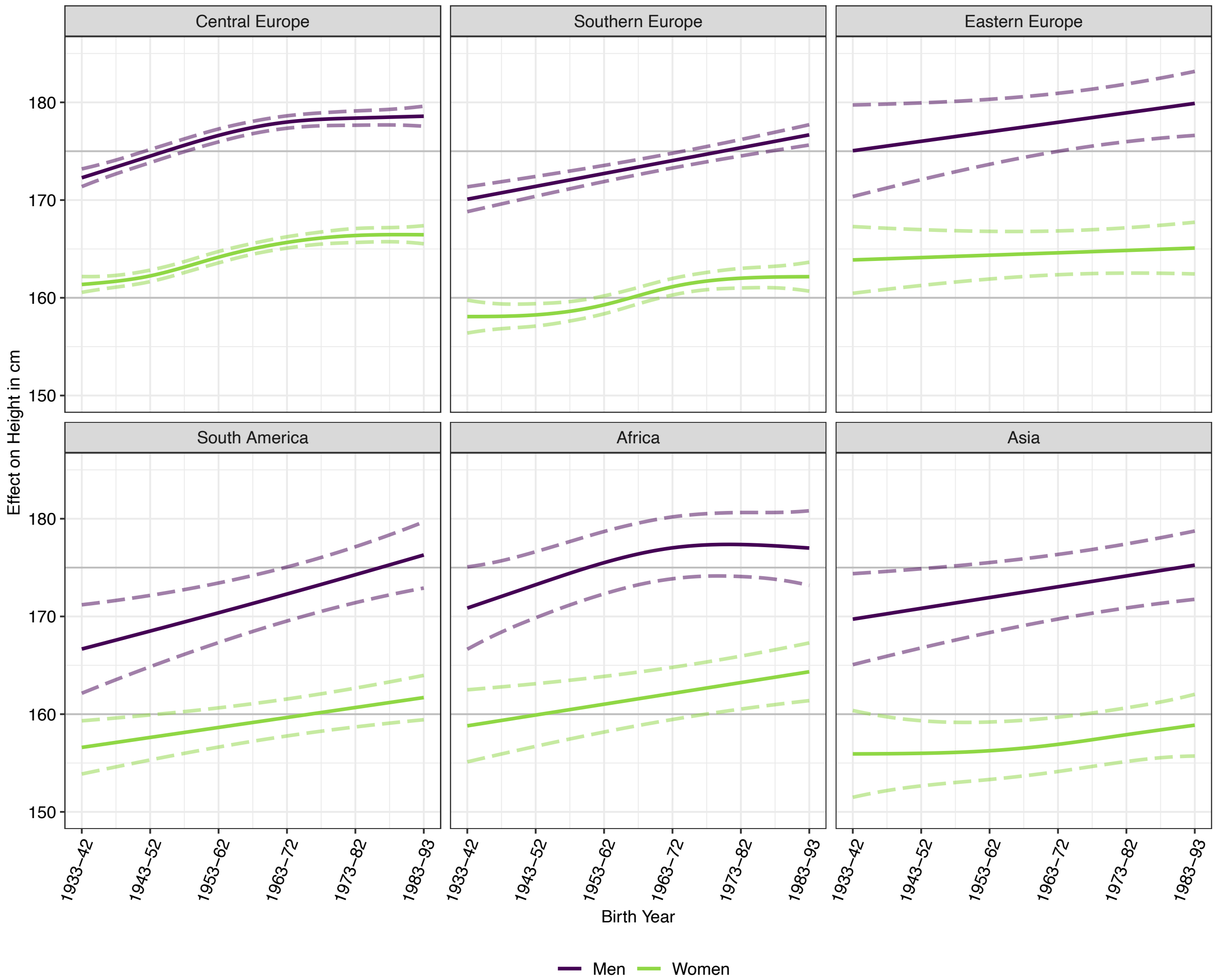
Supplementary Figure S2: Comparison of the adjusted and unadjusted trends shown in Figure 1 (purple and yellow lines, examination years 2005-2017), with unadjusted trends for the examination years 1992-2017 and published averages for young male conscripts (19 years old) from Geneva.



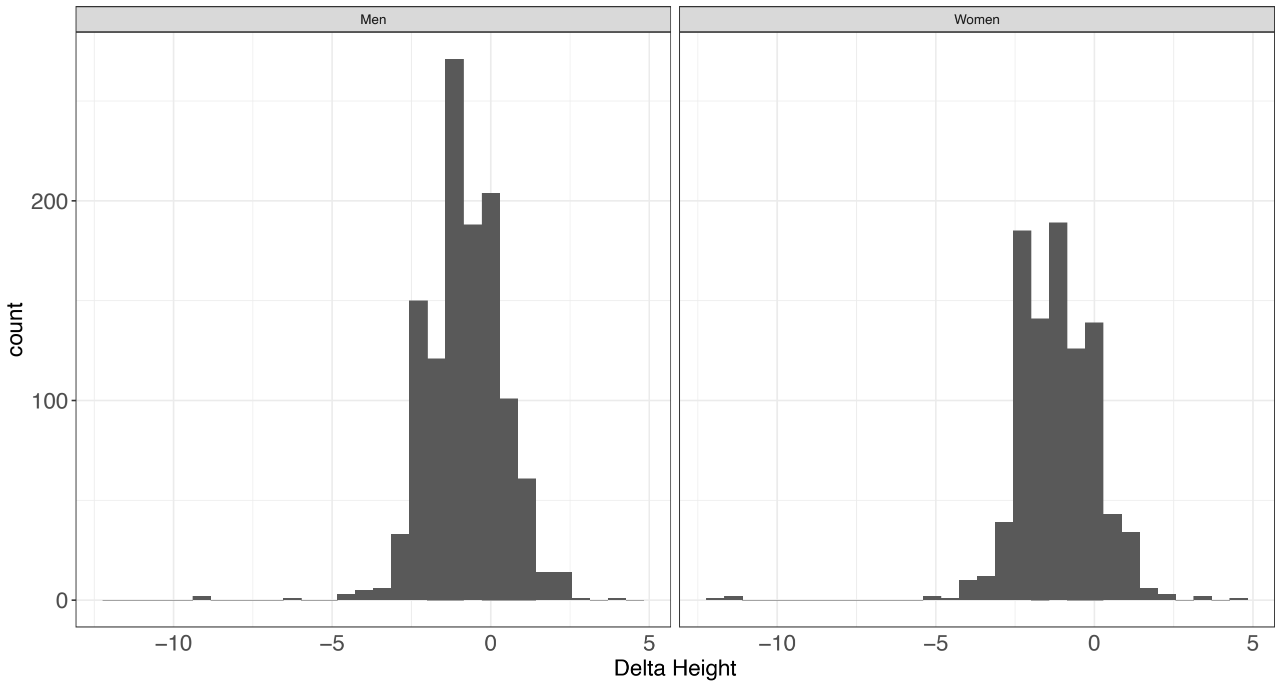
Supplementary Figure S3: Average height of adult male and female *Bus Santé* participants per ZIP code of residence within the city of Geneva (maps on the left side) compared to the average height of conscripts and average area-based Swiss-SEP (SSEP) index for the same areas (maps on the right side). The scatterplots with linear regression lines in the upper row of the graph indicate a positive correlation between average height and Swiss-SEP among ZIP codes.



Supplementary Figure S4: Modelled and adjusted trends for migration background across years of birth among adult men and women in Geneva.



Supplementary Figure S5: Histogram of height loss after age 50 years per year of follow-up in a subsample of *Bus Santé* participants of both sexes.



Reporting checklist for cross sectional study.

Based on the STROBE cross sectional guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the STROBE cross sectionalreporting guidelines, and cite them as:

von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies.

		Reporting Item	Page Number
Title and abstract			
Title	#1a	Indicate the study's design with a commonly used term in the title or the abstract	1
Abstract	#1b	Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background / rationale	#2	Explain the scientific background and rationale for the investigation being reported	3
Objectives	#3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	#4	Present key elements of study design early in the paper	4

Setting	[#5](#5)	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Eligibility criteria	[#6a](#6a)	Give the eligibility criteria, and the sources and methods of selection of participants.	7
	[#7](#7)	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources / measurement	[#8](#8)	For each variable of interest give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group. Give information separately for for exposed and unexposed groups if applicable.	5
Bias	[#9](#9)	Describe any efforts to address potential sources of bias	5
Study size	[#10](#10)	Explain how the study size was arrived at	7
Quantitative variables	[#11](#11)	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	5
Statistical methods	[#12a](#12a)	Describe all statistical methods, including those used to control for confounding	6
Statistical methods	[#12b](#12b)	Describe any methods used to examine subgroups and interactions	6
Statistical methods	[#12c](#12c)	Explain how missing data were addressed	6
Statistical methods	[#12d](#12d)	If applicable, describe analytical methods taking account of sampling strategy	5
Statistical methods	[#12e](#12e)	Describe any sensitivity analyses	7
Results			
Participants	[#13a](#13a)	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed. Give information separately for for exposed and unexposed groups if applicable.	7

Participants	#13b	Give reasons for non-participation at each stage	7
Participants	#13c	Consider use of a flow diagram	7
Descriptive data	#14a	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. Give information separately for exposed and unexposed groups if applicable.	7
Descriptive data	#14b	Indicate number of participants with missing data for each variable of interest	7
Outcome data	#15	Report numbers of outcome events or summary measures. Give information separately for exposed and unexposed groups if applicable.	7
Main results	#16a	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	7
Main results	#16b	Report category boundaries when continuous variables were categorized	7
Main results	#16c	If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	8
Other analyses	#17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	8
Discussion			
Key results	#18	Summarise key results with reference to study objectives	8
Limitations	#19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	9
Interpretation	#20	Give a cautious overall interpretation considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	8
Generalisability	#21	Discuss the generalisability (external validity) of the study results	9

Other Information

Funding	#22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	11

 This checklist was completed on 23. November 2021 using https://www.goodreports.org/, a tool made by the EQUATOR Network in collaboration with Penelope.ai

BMJ Open

Body height in adult women and men in a cross-sectional population-based survey in Geneva: Temporal trends, association with general health status, and height loss after age 50

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Primary Subject Heading:	Public health
Secondary Subject Heading:	Epidemiology
Keywords:	PUBLIC HEALTH, EPIDEMIOLOGY, STATISTICS & RESEARCH METHODS

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Body height in adult women and men in a cross-sectional population-based survey in Geneva: Temporal trends, association with general health status, and height loss after age 50

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Keywords: Stature; *Bus Santé* Study; Monitoring

Abstract

Objective: On the one hand, trends in average height in adulthood mirror changes in living standard and health status of a population and its subgroups; on the other hand, height in general, as well as the loss of height in older age in particular, are associated in different ways with outcomes for health. For these aspects, there is hardly any information for Switzerland based on representative and measured body height data.

Design: Repeated cross-sectional survey study.

Setting: Fully anonymized data from the representative population-based Geneva Bus Santé Study between 2005 and 2017 were analyzed.

Methods: Data from N=8,686 study participants were used in the trend analysis. Height was measured and socio-demographic information and self-rated health was collected via questionnaires. Follow-up (mean: 7.1 years) measurements from N=2,112 participants were available to assess height loss after age 50.

Results: Women were, on average, 166.2 cm (SD 6.5) tall, and men 179.2 cm (SD 6.5). Among men and women, higher socioeconomic status was associated with taller average height. The flattening of the increase in height from the 1970s birth years appears to begin earlier in the subgroup with the highest education level. The tallest average height was measured for men and women from Central and Northern Europe, the shortest for South America and Asia. The likelihood that participants rated their health as "very good" increased with greater body height. The follow-up data show that men lost -0.11 cm per follow-up year (95% CI -0.12 to -0.10), women -0.17 cm (95% CI -0.18 to 0.15).

Conclusions: The association of height and health status is currently understudied. Monitoring changes in average body height may indicate disparities in different subgroups of populations. Based on our study and a growing literature, we think that the multifaceted role of body height should be better considered in clinical practice.

Word count: 4556

Article summary

Strengths:

- Repeated representative and population-based cross-sectional study
- Measured body height using standardized protocols

Limitations:

- A healthy participant bias and remaining confounding cannot be excluded
- The number of follow-up measurements after age 50 is limited at the moment

1. Introduction

Adult height is the result of a dynamic and complex additive growth process [1,2]. The determinants include both genetics (responsible for up to 80%) and environmental factors (nutrition, disease environment, physical workload, socioeconomic background, etc.) [3]. Their interactions result in phenotypic variation [4]. Height is also connected with health in various ways, as it acts both as an indicator and as a possible determinant of health [5]. Body height has also practical importance in that it is one of the two equation variables in the calculation of body mass index, and thus significantly influences this measure, which is still widely used in the clinic.

The average height at various ages mirrors environmental conditions, such as nutrition, health and socioeconomic status [6]. For past and modern societies, changes in mean height or height distribution over decades and centuries reflect changes in health and well-being [7–9]. Improvements in access to food, dietary diversification, sanitation, water and living standards as well as decreases in exposure to diseases were found to be associated with the secular increase in height observed in the 19th and 20th centuries in Switzerland as well as in other European countries [5,10,11]. As height may be considered a proxy of health status, monitoring growth and height based on ongoing systematic public health surveillance can help identifying and tracking inequalities between population subgroups, thereby opening up fields for interventions [12–15].

Over the past 20-40 birth years, this steady secular increase in average height has plateaued or at least slowed [16]. Reasons for this development, despite the further growing standard of living, is not fully understood. Reaching the genetic limits [16], decreasing the amounts of proteins consumed and decreasing total energy intake [17] as well as increasing social inequality (which could prevent socially disadvantaged groups from realizing their hereditary growth potential) are potential explanations. There is a research gap regarding whether this plateauing takes place in all subpopulations of wealthier populations. One of the few studies assessing this topic investigated the connection between height and socio-economic background characteristics in Moroccan and Turkish children living in the Netherlands and showed that while the secular height increase in Dutch children came to a halt, the trend in Turkish and Moroccan children living in the Netherlands continued [18].

On the other hand, height is also a co-determinant of future health and well-being. Research on the association between adult height and mortality of specific diseases is generally heterogeneous [5,19]. Adult height displays both positive and negative associations with different disease-specific outcomes [19]. Overall, however, there is a negative relationship between all-cause mortality and height, even if it is not yet clear whether this effect is independent from other factors related to height (i.e., socio-economic factors) [5,11]. Therefore, height might influence not only physical health but also subjective well-being [5,20]. In addition, most people lose body height after age 40-50, and this adult height loss is in turn associated with negative health consequences later in life (bone health, cardiovascular health, general health status, etc.) [21–26].

Historical and recent developments in height in Switzerland have been described based on conscript data and through passport applications, maternity hospitals and prisoner data sources [16]. The literature shows that the secular increase since the end of the 19th century has been slowing down. However, it has not yet been determined whether this is the case for subpopulations defined by socioeconomic background, migration background, education level, etc. Previous studies were performed on Genevan conscripts [27] and discussed differences in height in terms of environmental and economic determinants [28]. However, as these studies were done on conscript data only, they represent merely a part of the population, namely, young Swiss men. These studies do not include women, nor do they include adults with migration backgrounds. Furthermore, there are few longer-running population-based health studies in Switzerland that include measured body heights.

In this study, we used data from a unique representative health survey of the Geneva general population and aimed to answer the following questions. First, using this large dataset, we wanted to investigate whether the slowdown in height increase in recent decades has affected all subgroups (education level and migration background) of the Geneva population. Second, we investigated whether height was associated with self-assessed health status. Third, in a small subsample, we were interested in whether and to what extent the Geneva population was affected by height loss.

2. Material and methods

For this paper, individual data from the *Bus Santé* study were used. *Bus Santé* is a population-based study conducted in Geneva, Switzerland, which was launched in 1993 and has been running ever since. Details on the study and the protocols are outlined in detail elsewhere [29]. Every year, a new representative sample of 500 men and 500 women is selected from the Geneva population using residential lists provided by the local government. Until 2009, a study population aged 34-75 was investigated; from 2010 on, the study age range was extended to 20-74 years. To be proportional to the corresponding population distributions, stratified random sampling in age and sex strata was performed. The study team reached out to individuals by mail, and if they were not responsive, they were called seven times. Then, two letters were sent. If they still could not be reached, they were replaced by another individual. However, if they refused to participate, they were not replaced. The 1995–2014 mean participation rate was 61% (range: 53%–69%) [30].

Each participant received several self-administered, standardized questionnaires covering the risk factors for major lifestyle chronic diseases, sociodemographic characteristics, educational and occupational histories and reproductive history for women. Each participant brought their completed questionnaires to one of the two study centres located in hospitals and one mobile examination bus visiting three parts of the Canton of Geneva, where the questionnaires were checked for correct filling by trained interviewers (nevertheless, the questionnaire data may contain missing values, for example, if persons did not want to or could not answer certain questions) [31]. Then, a comprehensive health assessment was performed, which also included several measurements (an overview is presented elsewhere [32]). Height was also measured in a temperature-controlled room in the standing position using a medical gauge (precision 1 cm) [33].

Variables in this study

With reference to our research questions (presented in the introduction), we worked with the following subdata sets from the *Bus Santé* study:

For most of our analyses, we focused on the examination years since 2005, when education level was available from the questionnaires. Measured and continuous body height (in cm) was the dependent variable for the time trend analysis. In terms of cofactors with relevance for height research, we used the nationality of the participants' parents to classify their migration background into six large groups: Central European (which also includes people with a Western European migration background), Southern European, Eastern European (which also includes people with a Southeast European migration background), South American, African and Asian. For all other migration backgrounds, the sample size was too small, so these migration backgrounds were combined into "Other". Both parents should have had the same migration background; if this was not the case (n=831 or 9.6%), they were also classified under "Other" because otherwise the number of resulting subgroups and combinations would have been too large and the associated sample sizes too small. To simplify the outputs, we only showed those where both parents had the same migration background and do not show the "Other" category. Following previous publications using *Bus Santé* data [34], education level was categorized into two groups, namely, in primary/secondary education (no degree or with a compulsory school degree, completed high school or apprenticeship) and in tertiary education (higher degree with a high school diploma). Additionally, information about the number of siblings was available (regarding resource allocation in childhood, this could also play a role in body growth, as has been shown for historical societies [35]). The number of siblings was divided into four groups ("none", "one", "two", "more"). Additionally, the years of birth were grouped in 10-year increments (1933-1942, 1943-1952, 1953-1962, 1963-1972, 1973-1982, 1983-1993).

The data also included the ZIP code of the residential address of the participants, which we used for our analysis by city neighbourhood within Geneva. To compare the average height in a given ZIP code with the area-based socioeconomic position of the ZIP code, we used the mean Swiss-SEP 2.0 (area-based index of socioeconomic position in Switzerland) per ZIP code. Swiss-SEP 2.0 indicates the average socioeconomic situation in a postal code and was developed and made available by the Institute for Social and Preventive Medicine at the University of Bern [36]. Additionally, published average heights of Swiss conscripts (18-22-year-old Swiss men, >90% coverage due to mandatory conscription, examination years 2010-2017) were used for comparison on the ZIP code level.

For our analysis of the association between height and health status, we used the summary self-reported statement from the questionnaires for this study as the dependent variable, and refrained from analysing the association between individual medical examinations and body height individually (this would be an important next step for specific follow-up studies). Self-rating answers to the questionnaire were grouped into four categories: “Very good”, “good”, “fair” and “bad/very bad”. For our analysis of adult height loss and to achieve the largest possible follow-up sample size, we also considered the earlier examination years from 1999-2005. For this smaller follow-up sample, the first examination took place in the years 1995-2003, and the follow-up examination was in 2005-2008.

We used the STROBE cross sectional reporting guidelines [37].

Ethics

For the entire *Bus Santé* study, all participants provided written informed consent, and *Bus Santé* was approved by the local institutional review board (Commission Cantonale d’Ethique de la Recherche de Genève; IRB00003116). Because the study owners provided only anonymized data to the study team for this article, no additional ethics approval was required.

Patient and Public Involvement

Patients or the public were not involved in the design, or recruitment, or conduct, or reporting, or dissemination plans of our research.

Statistical methods

All analyses were carried out separately for men and women. The unadjusted association between average height and Swiss-SEP of ZIP codes was displayed via maps and scatterplots.

To model trends and potentially nonlinear effects of cofactors, we used general additive models (GAMs). GAMs are an extension of generalized linear models obtained by allowing not only linear associations but also general smooth terms [38]. In our models, we used a smooth term for the independent variable year of birth. The fully adjusted model for the survey years 2005-2017 contained the following additional linear terms: year of survey, education, number of siblings, migration background of the mother and migration background of the father. In the next step, we stratified this analysis by migration background and educational level. In a sensitivity analysis, the 2005-2017 GAM was run unadjusted (only containing the smooth term year of birth) and compared to an equivalent model based on the full range of survey years 1995–2017. Furthermore, we also compared the men’s results with the published values of mean body heights of the conscripts (young Swiss men, 90% coverage).

To assess the association between height and self-rated health status, ordered logistic regression was used to predict probabilities of self-rated health status in relation to body height. The predictions of the probabilities were shown for mean age, primary/secondary education and migration background in Central Europe.

To examine the influence of each independent variable on body height and self-rated health status in the GAM and the ordered logistic regressions, we removed one independent variable from the model at a time and calculated the AIC (Akaike's information criterion). Next, the difference between the AIC for the full Model M and the model with omission of an independent variable k was calculated (i.e., ΔAICk=AICk-AIC_M). The larger ΔAICk is, the more important the variable is in the model.

To explore height loss, follow-up measurements of height were available in a small subsample of participants. For these participants, the first examination took place in 1995-2003, and the follow-up examination was in 2005-2008. We only included participants who were >=50 years old at the first examination and whose second examination was at least five years later. The reason for this approach was that height loss does not occur until the second half of life, and requires a certain follow-up duration for differences to manifest. The height loss was calculated as the delta height between the two examinations and standardized per year of follow-up. A one-sample two-sided t test with a 95% confidence interval was used to verify whether the height loss per 1-year follow-up differed from zero. The results are displayed per age group using boxplots.

3. Results

The initial sample 2005-2017 included n=10,585 participants. The inclusion/exclusion procedure is documented in Supplementary Figure S1. We excluded participants born before 1932 (n=17), with unrealistic height values <140 cm (n=24, range 16.3 to 133.0 cm) and >210 (n=8, range 267.0 to 795.1 cm), with missing data regarding height (n=282), parent's place of birth (n=1,442), education level (n=125) or number of siblings (n=18). The sample that we used for the trend analysis included n=8,686 participants (82.0% of the initial data), of which 51.7% were women. Female participants in this sample were, on average, 166.2 cm (SD 6.5) tall, and male participants were 179.2 cm (SD 6.5), both height distributions appear symmetrical (Supplementary Figure S2). The frequency distributions of the categorical variables are displayed in Table 1. Most of the participants were born between 1943 and 1982. The mean ages of males (49.3 years, SD 13.3) and females (49.1 years, SD 13.1) were similar. Women were slightly less likely to report secondary or tertiary education (43.2% in women vs. 47.0% in men, p<0.005 when using a chi-square test). The majority of the participants (51.0%) reported their nationality as Central Europe (including Switzerland). The second most frequent region was Southern Europe (20.8%), and other regions, such as Africa, Asia or South America, were less frequent (<6%). The majority of the participants had one or two siblings, and only 11.3% reported having no siblings.

Figure 1 shows the modelled trend of average height for men and women across birth years. When adjusting the model for all available cofactors which are relevant for body height, the level of average height is generally slightly higher. Both males and females grew taller over time. The adjusted trends show a slowdown in the increase in height from the birth years from the 1970s. In men, the most recent birth years again show a slight increase. A sensitivity analysis (Supplementary Figure S3) shows that the unadjusted trends from the 2005-2017 sample match the trends from the entire 1992-2017 sample well and, for males, they also match the averages from military conscription (young Swiss men from Geneva, 90% representativeness). Considering the cofactors in the models, the examination of Δ AIC shows that for men and women, migration background was the most important factor in explaining body height, followed by year of birth. For both sexes, education ranked third, and the number of siblings ranked fourth (Supplementary Table 1). The year of the survey was unimportant. When displaying the average Swiss-SEP of ZIP codes (as a proxy for area-based socioeconomic position) in the city of Geneva against the average height of participants living in those ZIP codes, we see a positive association. In higher Swiss-SEP ZIP Codes, men and women were taller on average (the same also accounts for conscripts, see Supplementary Figure S4).

A closer inspection of the trends by education level in Figure 2 (the models are again adjusted for the other co-factors) shows that people in the tertiary education group were taller than people in the primary/secondary education group. Moreover, the tertiary education group plateaued from 1963-1972, whereas people in the primary/secondary education group continued to grow taller. Among women, the difference between the tertiary and primary/secondary educational groups also narrows by birth years 1998-1993. Supplementary Figure S5 illustrates the differences in height trends according to migration background. Men and women from Central Europe (including Switzerland) and Eastern Europe were the tallest, whereas people from South America and Asia were the shortest. For people with Central European migration backgrounds, a height plateau was reached starting with birth years 1963-1972. For people with Southern European migration backgrounds, women's body height has stagnated since the 1963-1972 birth years, whereas men continue to grow taller.

To assess the association between height and self-rated health status, we had to exclude another n=1,749 participants for whom this information was missing in the dataset. Figure 3 illustrates the remaining data (n=6,937, 65.5% of the initial dataset). The probability of men and women rating their health status as "very good" increased with increasing body height (these models were again adjusted for the other co-factors. The results of the ΔAIC examination (Supplementary Table 1) revealed that body height was an important factor in describing self-rated health status. In women, body height was even more important than "age" in describing self-rated health status.

For a subsample of n=2,112 participants, follow-up measurements of height were available to estimate the height loss per 1-year follow-up. The mean delta in years between the two measurements was 7.1 years (SD 1.8) (the distribution of height loss are presented as histograms in Supplementary Figure S6). Overall, men lost -0.11 cm per year of follow-up (95% CI -0.12 to -0.10, p<0.001), and women lost -0.17 cm (95% CI -0.18 to 0.15, p<0.001). Thus, women lost on average -0.06 cm (95% CI -0.07 to -0.04 cm, p<0.001) more than men. Figure 4 shows that the older the participant was at the first examination, the greater the height loss was when re-examined.

4. Discussion

Measured and representative information on the height of adult men and women is rarely available, especially in regard to the question of whether within European countries, growth of all subgroups of a population have slowed down or become steadily taller. Here, we analysed body height in a unique population-based and sufficiently large dataset 2005-2017 from the Swiss city of Geneva. We found that both men and women have become significantly taller across birth years in the 20th century but that this increase has slowed down since the 1970 birth years. Migration background and year of birth were the most important explanatory factors for height, followed by education level. We also found a positive association between average height and area-based SEP across ZIP codes within the city. Men and women with migration backgrounds in Central and Eastern Europe were the tallest, and participants with migration backgrounds in South America and Asia were the shortest. In terms of time trends and slowdown of increase, we see some differences by subgroup (education level and migration background). Furthermore, taller height was an important cofactor in explaining better self-rated health status. In a follow-up sample, we showed that participants over the age of 50 lost height over time.

In this study, we showed that even in an urban population, the slowdown in the increase in body height since the 1970s birth cohorts, which has already been shown for Switzerland as a whole, is confirmed. The Geneva data we presented here are reliable in that they are based on objectively measured heights in a representative and relatively large dataset (which was less the case in the mentioned Switzerland-wide study) [39]. We showed that there are differences in recent height trends between education levels and migration groups in Geneva. For example, we observed that on average, taller people with tertiary education stopped growing taller in height earlier than people with lower education levels. In the youngest birth cohorts included in the *Bus Santé* study, we can even observe a closing of this height gap between the education levels. Whether this continues or whether the youngest study participants have simply not yet completed their education will become clear in the coming years. That there are differences in these rather recent height trends according to the subgroups of a population has already been shown for the Netherlands, where the secular height increase in Dutch children has come to a halt, whereas the trend continued in Turkish and Moroccan children living in the Netherlands [18]. The models in our study suggest that year of birth and migration background are particularly strong co-factors. This can be explained, on the one hand, by the fact that body height has a strong genetic component [40] and there are large differences in mean body height between world regions, and, on the other hand, the increase in mean body height until the second half of the 20th century was more than 10-15 cm overall, especially in Western countries [41]. This knowledge of these important influencing factors, as well as knowledge of current trends in body height, should be included in clinical practice in the assessment of general health status, especially when body height itself is associated with health in various ways (see further below), or is included as a variable, for example, in the calculation of a body mass index.

The differences in average body height by ZIP code within the city of Geneva and the spatial correspondence with higher and lower socioeconomic neighbourhoods that we have shown are consistent with other studies that have examined other health-related aspects in the *Bus Santé* study on a small-scale basis: Geneva neighbourhoods where the average height was taller also tended to be neighbourhoods where the obesity rate or sweetened beverage (SB) intake was lower [30,42]. This is an indication that the social topography within a city is an important cofactor in studies of this kind. For Switzerland as a whole, ZIP code clusters of taller and shorter people had already been documented on the basis of conscripts in earlier studies [43]. The results presented here add to this literature by showing that this concept is also important within cities. For now, it must remain an open question to what extent clusters of certain cultural, socioeconomic, and migration-related factors in certain neighbourhoods are the drivers behind these patterns.

We add to existing studies which found an association between health and adult height. This association is also reflected in the broad literature showing an overall negative relationship between all-cause mortality and height [5,11]. This basic mortality pattern had already been confirmed for Switzerland as well [10]. Data on morbidity also point in the same direction, although here, as with causes of death, important differentiations must be made according to diseases: On the one hand, taller height has been shown to be associated with better cardiovascular health. Explanations include, among others, larger coronary vessel diameters, elevated insulin-like growth factors, slower heart rate, and/or greater lung capacity in taller people [44]. On the other hand, a growing number of studies and meta-analyses show that taller body height is associated with an increased risk for some types of cancers [45]. The explanations here go in the direction of a larger number of cells in taller people as well as hormonal aspects again [5]. Another arm of the literature also shows that height trajectories, especially in the second half of life, are associated with bone health later in life (see next paragraph) [46]. Such objective aspects are, in our view, also reflected to some extent in the subjective self-assessment of overall health. Here, future studies using the *Bus Santé* data could go into more depth when the associations between individual objective medical examinations and body height are examined in more detail. If it is confirmed that body height is indeed a previously rather underestimated co-factor in the clinic, this should be more widely communicated to practitioners.

Height loss in adulthood has not been studied in Switzerland for 70 years [47]. The present study is the first to revisit this topic for Switzerland and to provide an indication that this health-related aspect for elderly people should be studied more broadly. The descriptive results presented here for Geneva are consistent with previous literature in that height loss increased with increasing age and that women were generally more affected by height loss than men [21,22,24–26,48]. The latter phenomenon could be influenced by menopause (possibly also hormonal influences) or by the generally higher risk in women of poorer bone health later in life [48]. Among the reasons for height loss are weakening of muscle groups, postural changes, disc degeneration, frailty, joint space narrowing, spinal deformities, and kyphosis [48]. If further studies confirm the relevance of height loss as a factor for later health [25,26], then height measurements and assessment of height loss should provide important information for clinical practice [46] and should be part of the regular examinations from the age of 40 or 50 to monitor health status in general, especially in the case of severe height loss, and more often among women than men.

The strengths of this study clearly lie in the underlying, unique data material. There are few rolling representative population-based studies of this sample size with precisely measured body heights (including partial follow-up measurements). Another advantage is that the migration background was included more precisely than usual via the parents' place of birth. In terms of limitations, the following points should be noted. First, information on the important variable education level has only been collected since 2005. However, the remaining study size was still large enough to answer the research questions. Second, population-based health studies have tended to struggle with declining participation rates in recent years. This is only partly the case with *Bus Santé*, as much time and effort have been invested by the study operators in participant recruitment. It cannot be ruled out that *Bus Santé*, like other similar studies, also exhibits a healthy participant bias in which unhealthier people may be more likely not to participate. Third, the association between body height and health status examined here was only a first step in this direction. Future studies could go into more depth here by focusing on individual health examinations from the broad measurement battery performed in the *Bus Santé* study. It is clear that the self-assessed general health variable used here is subjective and can only provide a first summarizing indication. Fourth, the height loss follow-up sample studied here was still too small. In the future course of the *Bus Santé* study, it will be interesting to include further follow-up measurements as well as link height loss with health outcomes later in life. Fifth, in observational study causality cannot determined. It is also possible that, despite the use of adjusted models, certain results were still influenced by remaining confounding factors.

Conclusion

In research on body height, current trends and associations with health have not been sufficiently considered. For example, trend monitoring by subgroups within certain populations reveals that not all subgroups seem to slowdown in getting taller, and there may be differences by education level and migration background. This also points in the direction of the relevance of social inequality in this context, which can also be mirrored and monitored to some extent by such height trends. Mean body height seems to be a good measure of deficiency (as long as the genetic growth potential is not yet exhausted) but less abundant (than mean body height plateaus). Moreover, the effects of body height on health are still considered too little in the public health field. This is especially true for height loss in the second half of life, where better data are needed.

Author statements

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Data sharing statement: Consent has not been obtained to share the data publicly. However, data may be accessed on contacting the study team (https://www.hug.ch/medecine-premier-recours/bus-sante). The statistical analysis scripts can be obtained by contacting the corresponding author.

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Bibliography

1 Wells JC. Worldwide variability in growth and its association with health: Incorporating body composition, developmental plasticity, and intergenerational effects. *Am J Hum Biol* 2017;**2017-01–22**.

2 Tanner JM. *Foetus into Man. Physical Growth from Conception to Maturity*. 2nd ed. Cambridge, Mass.: : Harvard University Press 1990.

3 Bogin B. *Patterns of human growth*. 2nd ed. Cambridge: : Cambridge University Press 1999.

4 Floud R, Fogel R, Harris B, *et al. The changing body: health, nutrition, and human development in the Western world since 1700*. Cambridge: : Cambridge Univ. Press 2011.

5 Perkins JM, Subramanian S V., Smith GD, *et al.* Adult height, nutrition, and population health. *Nutr Rev* 2016;**74**:149–65. doi:10.1093/nutrit/nuv105

6 Kues AB. Taller - Healthier - more equal? The biological standard of living in Switzerland in the second half of the 20th century. *Econ Hum Biol* 2010;**8**:67–79. doi:10.1016/j.ehb.2009.09.002

7 Cole TJ. The secular trend in human physical growth: a biological view. *Econ Hum Biol* 2003;**1**:161–8. doi:S1570677X02000333 [pii]10.1016/S1570-677X(02)00033-3

8 Gausman J, Meija Guevara I, Subramanian S V., *et al.* Distributional change of women's adult height in low- and middle-income countries over the past half century: An observational study using cross-sectional survey data. *PLOS Med* 2018;**15**:e1002568.

9 Komlos J. Anthropometric history: an overview of a quarter century of research. *Anthr Anz* 2009;**67**:341–56.

10 Rohrmann S, Haile SR, Staub K, *et al.* Body height and mortality - mortality follow-up of four Swiss surveys. *Prev Med (Baltim)* Published Online First: 2017. doi:10.1016/j.ypmed.2017.05.023

11 Gausman J, Meija Guevara I, Subramanian S V., *et al.* Distributional change of women's adult height in low- and middle-income countries over the past half century: An observational study using cross-sectional survey data. *PLOS Med* 2018;**15**:e1002568. doi:10.1371/journal.pmed.1002568

12 Groseclose SL, Buckeridge DL. Public Health Surveillance Systems: Recent Advances in Their Use and Evaluation. *Annu Rev Public Health* 2017;**38**:57–79. doi:10.1146/annurev-publhealth-031816-044348

13 German RR, Lee LM, Horan JM, *et al.* Updated guidelines for evaluating public health surveillance systems: recommendations from the Guidelines Working Group. *Recomm reports Morb Mortal Wkly Rep* 2001;**50**:1–35.http://www.ncbi.nlm.nih.gov/pubmed/18634202 (accessed 4 Jan 2017).

14 Grantham-McGregor S, Powell C, Walker S. Nutritional supplements, stunting, and child development. *Lancet* 1989;**2**:809–10.http://www.ncbi.nlm.nih.gov/pubmed/2571055

15 Tanner JM. The potential of auxological data for monitoring economic and social well-being. *Soc Sci Hist* 1982;**6**:571–81.

16 Vinci L, Floris J, Koepke N, *et al.* Have Swiss adult males and females stopped growing taller? Evidence from the population-based nutrition survey menuCH, 2014/2015. *Econ Hum Biol*

2019;**33**:201–10. doi:10.1016/J.EHB.2019.03.009

17 Abreu D, Cardoso I, Gaspoz JM, *et al.* Trends in dietary intake in Switzerland, 1999 to 2009. *Public Health Nutr* Published Online First: 2014. doi:10.1017/S1368980013000207

18 Schönbeck Y, van Dommelen P, HiraSing RA, *et al.* Trend in Height of Turkish and Moroccan Children Living in The Netherlands. *PLoS One* 2015;**10**:e0124686. doi:10.1371/journal.pone.0124686

19 Wormser D, Di Angelantonio E, Kaptoge S, *et al.* Adult height and the risk of cause-specific death and vascular morbidity in 1 million people: Individual participant meta-analysis. *Int J Epidemiol* Published Online First: 2012. doi:10.1093/ije/dys086

20 Coste J, Pouchot J, Carel JC. Height and health-related quality of life: A nationwide population study. *J Clin Endocrinol Metab* Published Online First: 2012. doi:10.1210/jc.2012-1543

21 Hannan MT, Broe KE, Cupples LA, *et al.* Height loss predicts subsequent hip fracture in men and women of the Framingham Study. *J Bone Miner Res* 2012;**27**:146–52. doi:10.1002/jbmr.557

22 Sorkin JD, Muller DC, Andres R. Longitudinal Change in Height of Men and Women: Implications for Interpretation of the Body Mass Index: The Baltimore Longitudinal Study of Aging. *Am J Epidemiol* 1999;**150**:969–77. doi:10.1093/oxfordjournals.aje.a010106

23 Moayyeri A, Kaptoge S, Luben RN, *et al.* Estimation of absolute fracture risk among middle-aged and older men and women: the EPIC-Norfolk population cohort study. *Eur J Epidemiol* 2009;**24**:259–66. doi:10.1007/s10654-009-9337-8

24 Pluskiewicz W, Adamczyk P, Drozdzowska B. The significance of height loss in postmenopausal women. The results from GO Study. *Int J Clin Pract* 2021;**75**. doi:10.1111/ijcp.14009

25 Masunari N, Fujiwara S, Nakata Y, *et al.* Historical height loss, vertebral deformity, and health-related quality of life in Hiroshima cohort study. *Osteoporos Int* 2007;**18**:1493–9. doi:10.1007/s00198-007-0392-2

26 Wannamethee SG. Height Loss in Older Men. *Arch Intern Med* 2006;**166**:2546. doi:10.1001/archinte.166.22.2546

27 Staub K, Rühli FJ. 'From growth in height to growth in breadth': the changing body shape of Swiss conscripts since the late 19th century and possible endocrine explanations. *Gen Comp Endocrinol* 2013;**188**:9–15. doi:10.1016/j.ygcen.2013.03.028

28 Staub K, Rühli FJ, Bogin B, *et al.* Edouard Mallet's early and almost forgotten study of the average height of Genevan conscripts in 1835. *Econ Hum Biol* Published Online First: 2011. doi:10.1016/j.ehb.2011.03.001

29 Sandoval JL, Leão T, Theler J-M, *et al.* Alcohol control policies and socioeconomic inequalities in hazardous alcohol consumption: a 22-year cross-sectional study in a Swiss urban population. *BMJ Open* 2019;**9**:e028971. doi:10.1136/bmjopen-2019-028971

30 Joost S, De Ridder D, Marques-Vidal P, *et al.* Overlapping spatial clusters of sugar-sweetened beverage intake and body mass index in Geneva state, Switzerland. *Nutr Diabetes* 2019;**9**:35. doi:10.1038/s41387-019-0102-0

31 Dumont S, Marques-Vidal P, Favrod-Coune T, *et al.* Alcohol policy changes and 22-year trends in individual alcohol consumption in a Swiss adult population: A 1993-2014 cross-sectional population-based study. BMJ Open. 2017. doi:10.1136/bmjopen-2016-014828

32 Schneid Schuh D, Guessous I, Gaspoz J-M, *et al.* Twenty-four-year trends and determinants of change in compliance with Swiss dietary guidelines. *Eur J Clin Nutr* 2019;**73**:859–68. doi:10.1038/s41430-018-0273-0

33 Guessous I, Bochud M, Theler JM, *et al.* 1999-2009 trends in prevalence, unawareness, treatment and control of hypertension in Geneva, Switzerland. *PLoS One* Published Online First: 2012. doi:10.1371/journal.pone.0039877

34 Guessous I, Bochud M, Theler JM, *et al.* 1999-2009 Trends in prevalence, unawareness, treatment and control of hypertension in Geneva, Switzerland. *PLoS One* 2012;**7**:e39877. doi:10.1371/journal.pone.0039877

35 Mazzoni S, Breschi M, Manfredini M, *et al.* The relationship between family characteristics and height in Sardinia at the turn of the twentieth century. *Hist Fam* 2017;**22**:291–309. doi:10.1080/1081602X.2016.1230509

36 Panczak R, Galobardes B, Voorpostel M, *et al.* A Swiss neighbourhood index of socioeconomic position: development and association with mortality. *J Epidemiol Community Health* 2012;**66**:1129–36. doi:10.1136/jech-2011-200699

37 von Elm E, Altman DG, Egger M, *et al.* The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *J Clin Epidemiol* 2008;**61**:344–9. doi:10.1016/j.jclinepi.2007.11.008

38 Wood S. *Generalized additive models: an introduction with R*. 2nd ed. Boca Raton, Fla: : Chapman and Hall/CRC 2017.

39 Vinci L, Floris J, Koepke N, *et al.* Have Swiss adult males and females stopped growing taller? Evidence from the population-based nutrition survey menuCH, 2014/2015. *Econ Hum Biol* 2019;**33**. doi:10.1016/j.ehb.2019.03.009

40 Wood AR, Esko T, Yang J, *et al.* Defining the role of common variation in the genomic and biological architecture of adult human height. *Nat Genet* 2014;**46**:1173–86.

41 (NCD-RisC) NRFC. A century of trends in adult human height. *Elife* 2016;**5**. doi:10.7554/eLife.13410

42 Guessous I, Joost S, Jeannot E, *et al.* A comparison of the spatial dependence of body mass index among adults and children in a Swiss general population. *Nutr Diabetes* 2014;**4**:e111. doi:10.1038/nutd.2014.8

43 Panczak R, Moser A, Held L, *et al.* A tall order: Small area mapping and modelling of adult height among Swiss male conscripts. *Econ Hum Biol* 2017;**26**. doi:10.1016/j.ehb.2017.01.005

44 Islam MT, Siraj MS, Hassan MZ, *et al.* Influence of height on blood pressure and hypertension among Bangladeshi adults. *Int J Cardiol Hypertens* 2020;**5**. doi:10.1016/j.ijchy.2020.100028

45 Giovannucci E. A growing link—what is the role of height in cancer risk? *Br J Cancer*

2019;**120**:575–6. doi:10.1038/s41416-018-0370-9

46 Pluskiewicz W, Adamczyk P, Drozdzowska B. Height loss in postmenopausal women—do we need more for fracture risk assessment? Results from the GO Study. *Osteoporos Int* 2021;**32**:2043–9. doi:10.1007/s00198-021-05941-3

47 Büchi E. *Änderungen der Körpeform beim erwachsenen Menschen. Eine Untersuchung nach der Individual-Methode*. Horn, Wien: : Verlag Ferdinand Berger 1950.

48 Shimizu M, Kobayashi T, Chiba H, *et al.* Adult spinal deformity and its relationship with height loss: a 34-year longitudinal cohort study. *BMC Musculoskelet Disord* 2020;**21**:422. doi:10.1186/s12891-020-03464-2

Table 1: Descriptive statistics of the *Bus Santé* study population (examination years 2005-2017) after excluding missing values (see flow chart in Appendix Figure 1).

		Men (N=4199)	Women (N=4487)	Total (N=8686)
Year of birth	1933-1942	330 (7.9%)	330 (7.4%)	660 (7.6%)
	1943-1952	792 (18.9%)	837 (18.7%)	1629 (18.8%)
	1953-1962	910 (21.7%)	990 (22.1%)	1900 (21.9%)
	1963-1972	1211 (28.8%)	1233 (27.5%)	2444 (28.1%)
	1973-1982	565 (13.5%)	655 (14.6%)	1220 (14.0%)
	1983-1993	391 (9.3%)	442 (9.9%)	833 (9.6%)
Education	Primary/Secondary	2226 (53.0%)	2549 (56.8%)	4775 (55%)
	Tertiary	1973 (47.0%)	1938 (43.2%)	3911 (45%
Region	Africa	253 (6.0%)	223 (5.0%)	476 (5.5%)
	Asia	140 (3.3%)	166 (3.7%)	306 (3.5%)
	Central Europe	2089 (49.7%)	2344 (52.2%)	4433 (51.0%)
	Eastern Europe	137 (3.3%)	146 (3.3%)	283 (3.3%)
	Other	438 (10.4%)	499 (11.1%)	937 (10.8%)
	South America	143 (3.4%)	301 (6.7%)	444 (5.1%)
	Southern Europe	999 (23.8%)	808 (18.0%)	1807 (20.8%)
Siblings	None	459 (10.9%)	519 (11.6%)	978 (11.3%)
	One	1525 (36.3%)	1641 (36.6%)	3166 (36.4%)
	Two	934 (22.2%)	948 (21.1%)	1882 (21.7%)
	More	1281 (30.5%)	1379 (30.7%)	2660 (30.6%)

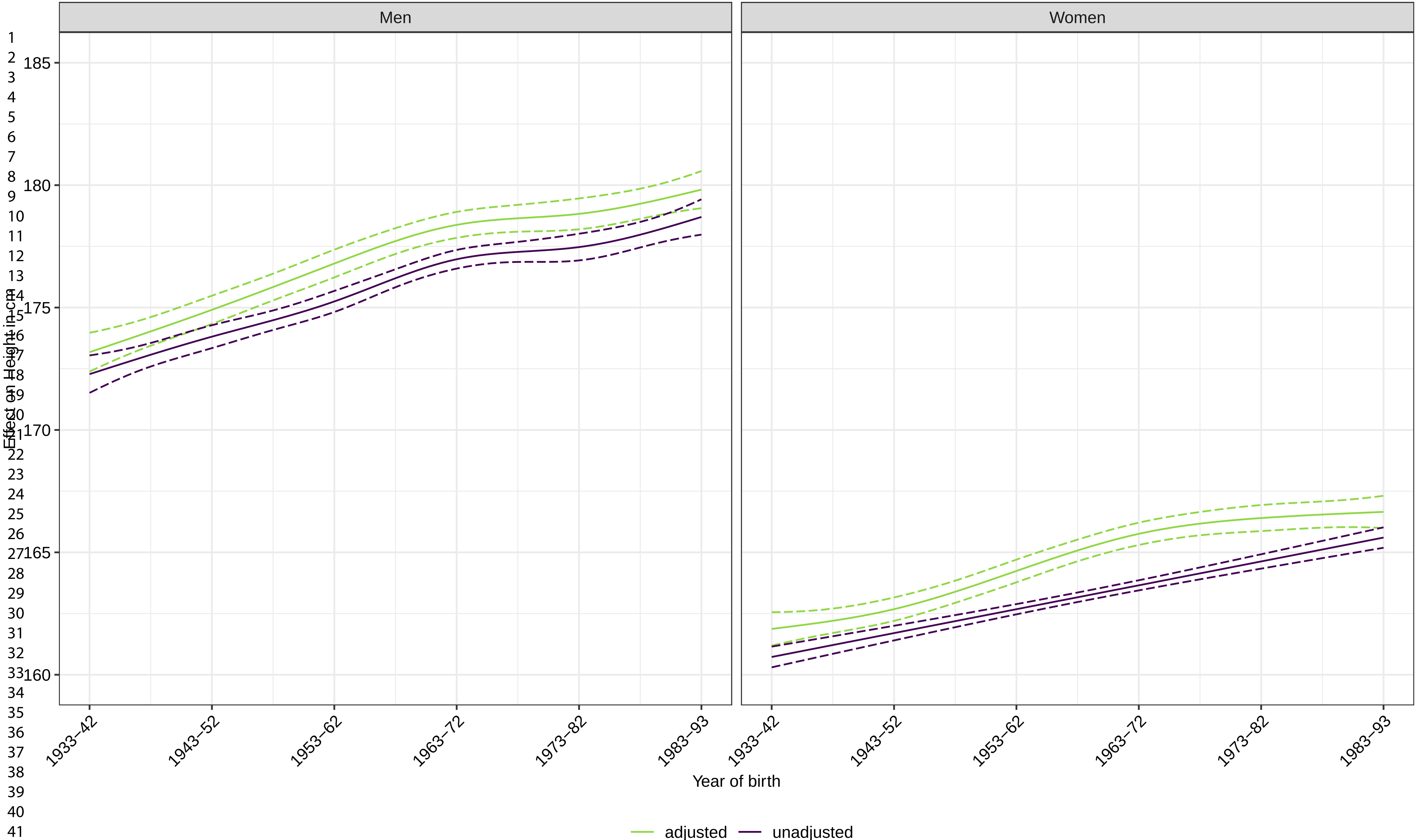
Figure legends

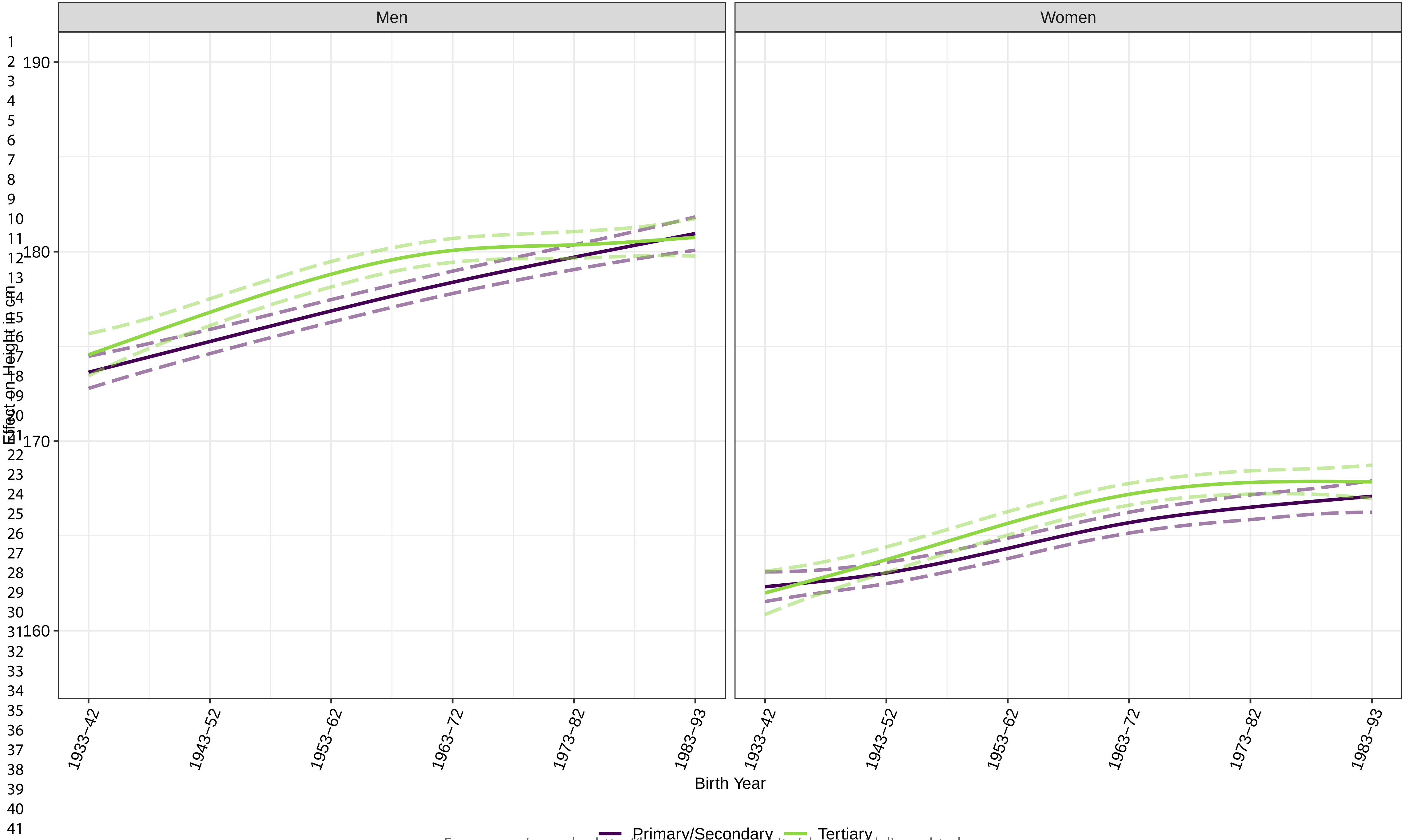
Figure 1: Modelled overall trends (unadjusted vs. adjusted) of average height across birth years among adult men (n=4199) and women (n=4487) in Geneva.

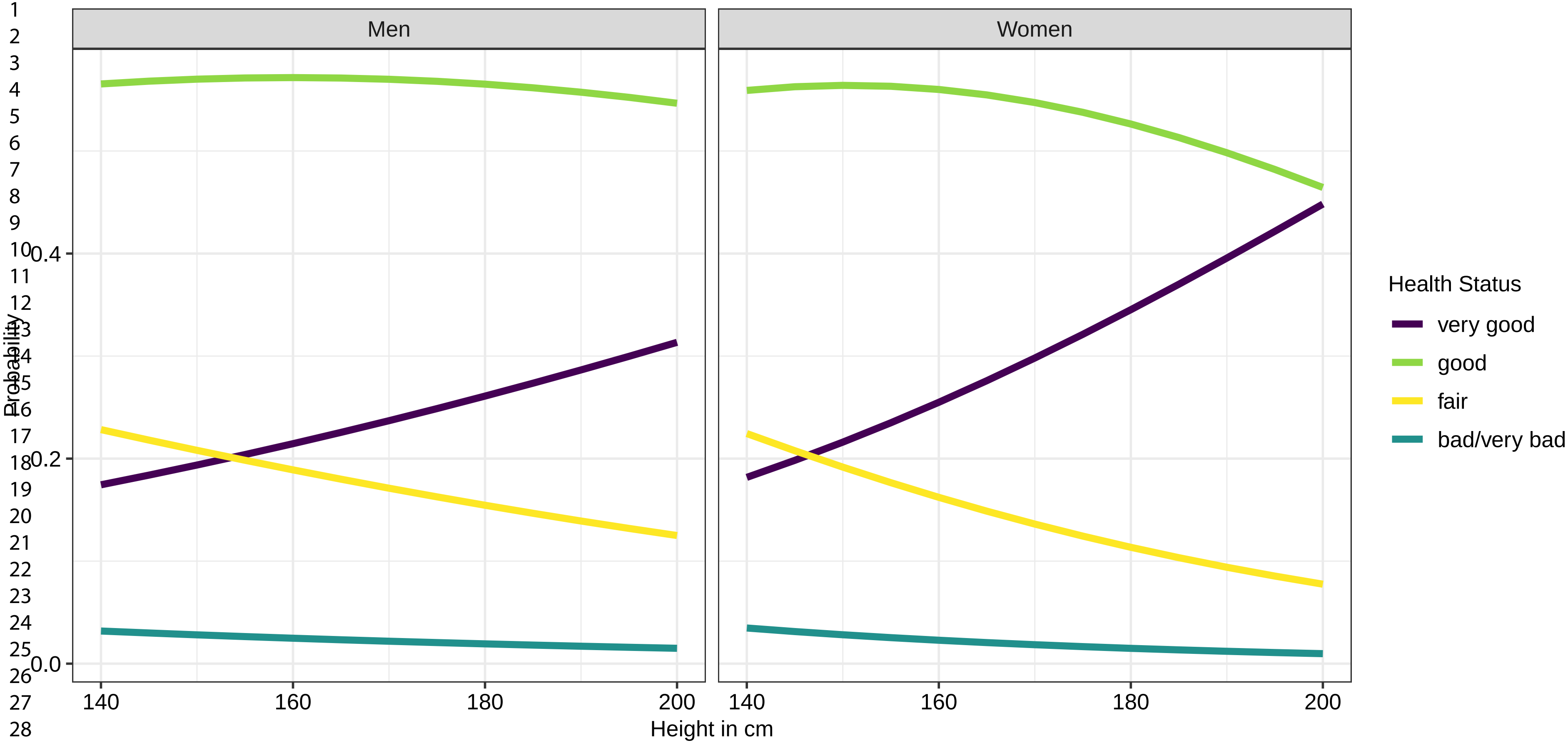
Figure 2: Modelled and adjusted trends for educational levels across years of birth among adult men and women in Geneva.

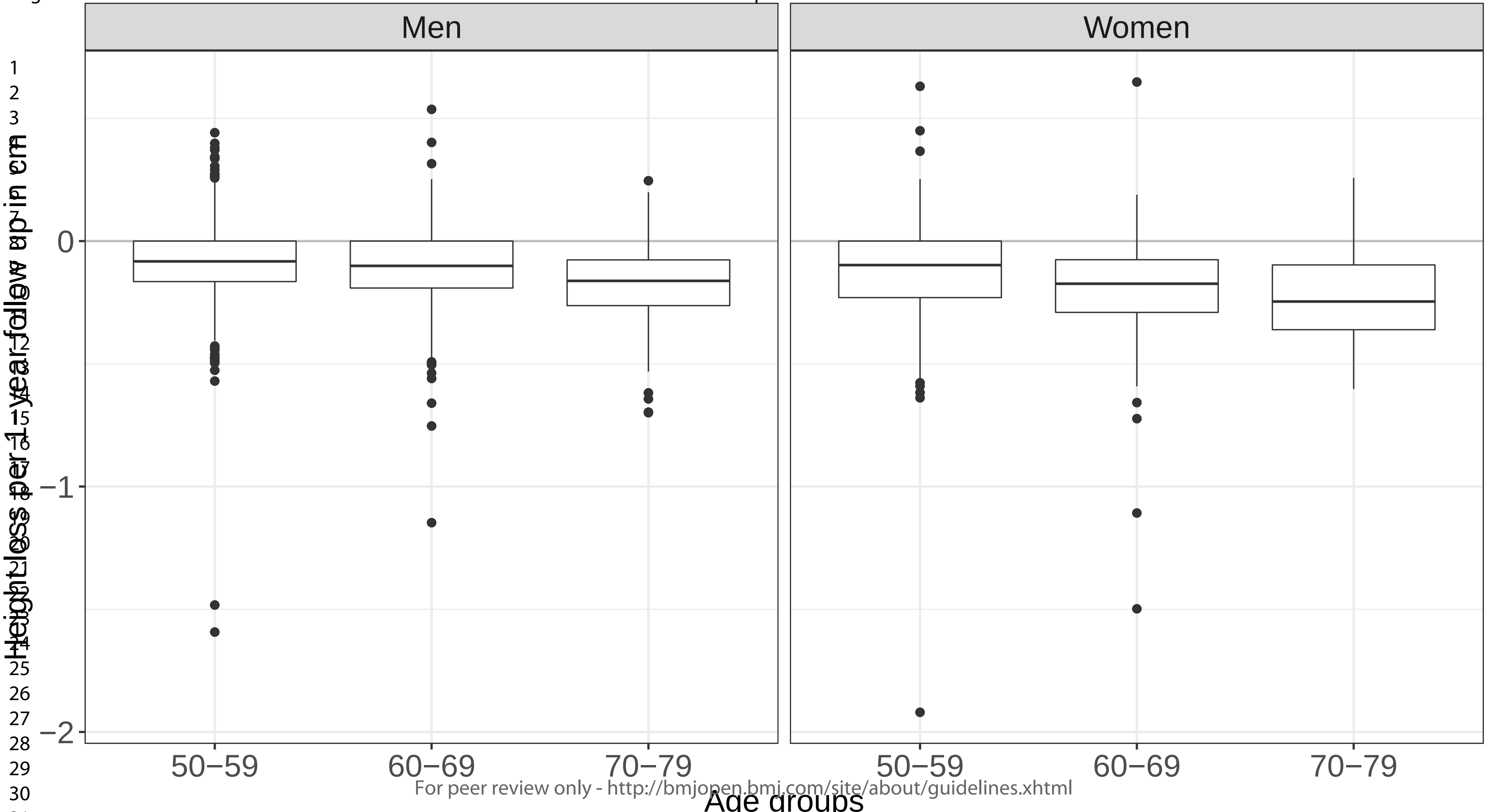
Figure 3: The probabilities of belonging to specific self-declared health status groups (lines) across the height spectrum (x-axis). The probabilities are shown for median age, primary/secondary education, Swiss nationality, and migration background in Central Europe.

Figure 4: Boxplots for height loss after age 50 years per year of follow-up across baseline age groups in a subsample of *Bus Santé* participants of both sexes.


Men
Women
185
180
175
170
165
160
Effect on Height in cm
1933–42
1943–52
1953–62
1963–72
1973–82
1983–93
Year of birth
adjusted
unadjusted


Men
Women
190
180
170
160
Effect on Height in cm
1933–42
1943–52
1953–62
1963–72
1973–82
1983–93
Birth Year
Primary/Secondary
Tertiary


Men
Women
Probability
0.0
0.2
0.4
140
160
180
200
Height in cm
Health Status
very good
good
fair
bad/very bad


Men
Women
0
−1
−2
50−59
60−69
70−79
50−59
60−69
70−79
Height loss per 1-year follow up in cm
Age groups

Supplementary Material to:

Schäppi et al.: Body height in adult women and men in a cross-sectional population-based survey in Geneva: Temporal trends, association with general health status, and height loss after age 50

Supplementary Table S1: The results of the Δ AIC examination. The lower the Δ AIC the lower the importance of a given variable in a model.

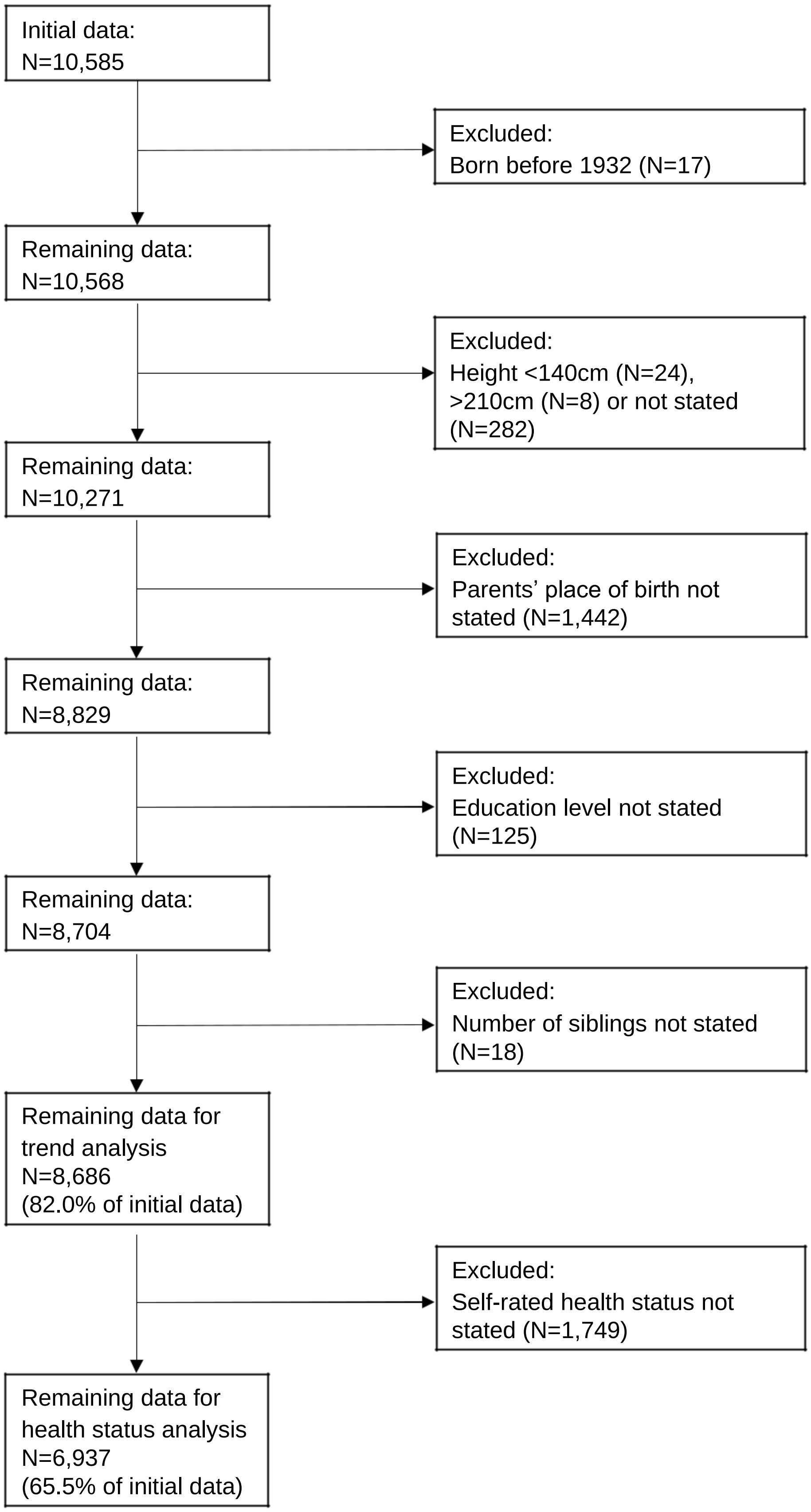
A) Models explaining height trends

Men		**Women**	
Parameter	**Δ AIC**	**Parameter**	**Δ AIC**
Migration	359.0	Migration	555.9
Birthyear	283.6	Birthyear	236.9
Education	91.6	Education	67.5
Sibling	31.6	Sibling	22.3
Examin. Year	0.7	Examin. Year	-1.9

B) Models explaining health status

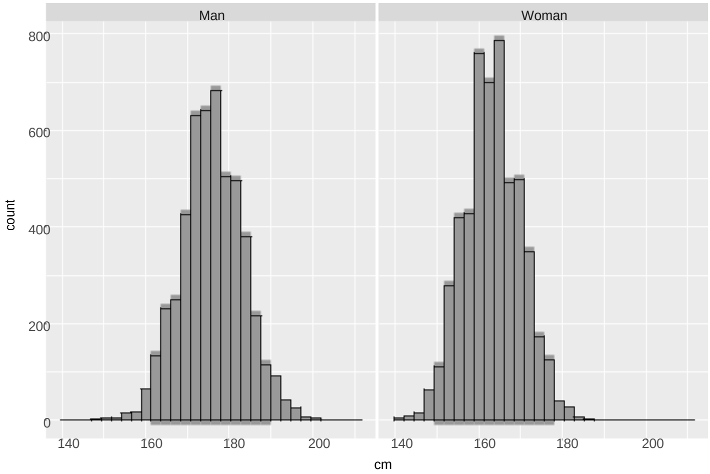
Men		**Women**	
Parameter	**Δ AIC**	**Parameter**	**Δ AIC**
Education	37.5	Migration	54.5
Age	35.5	Education	21.0
Migration	14.8	Height	14.8
Height	4.5	Age	7.9

Supplementary Figure S1: Flow chart of data preparation.

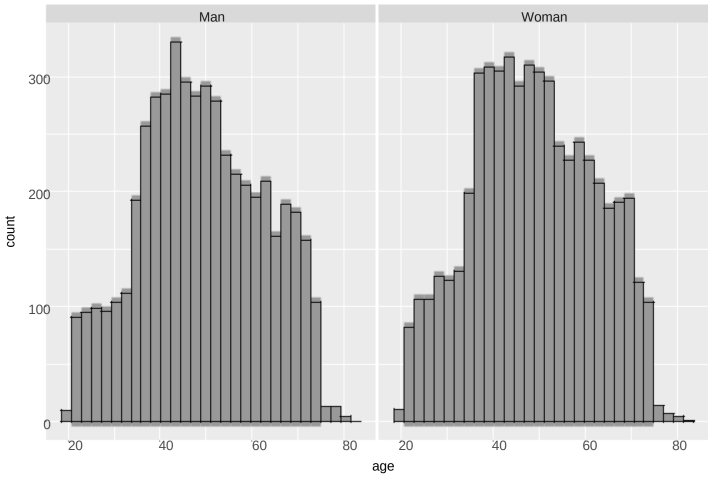


Supplementary Figure S2: Histogram of height (A) and age (B).

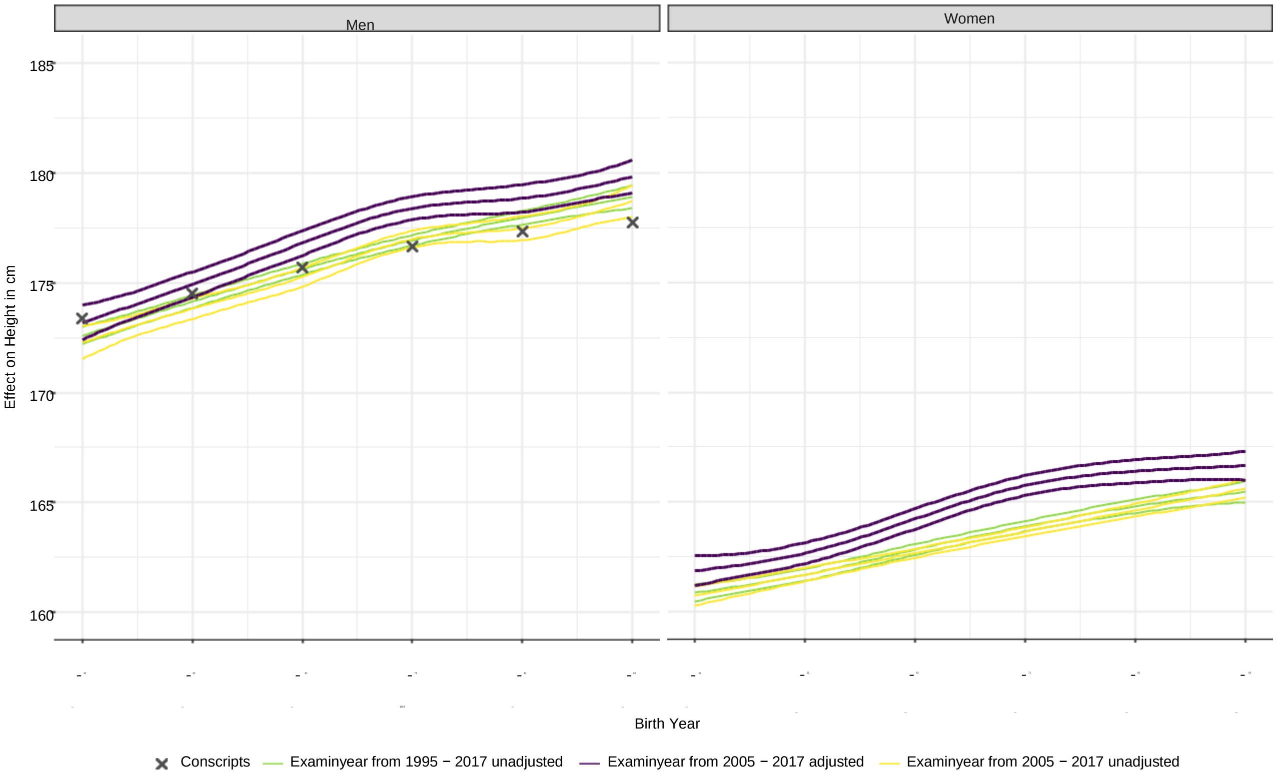
A) Histogram height



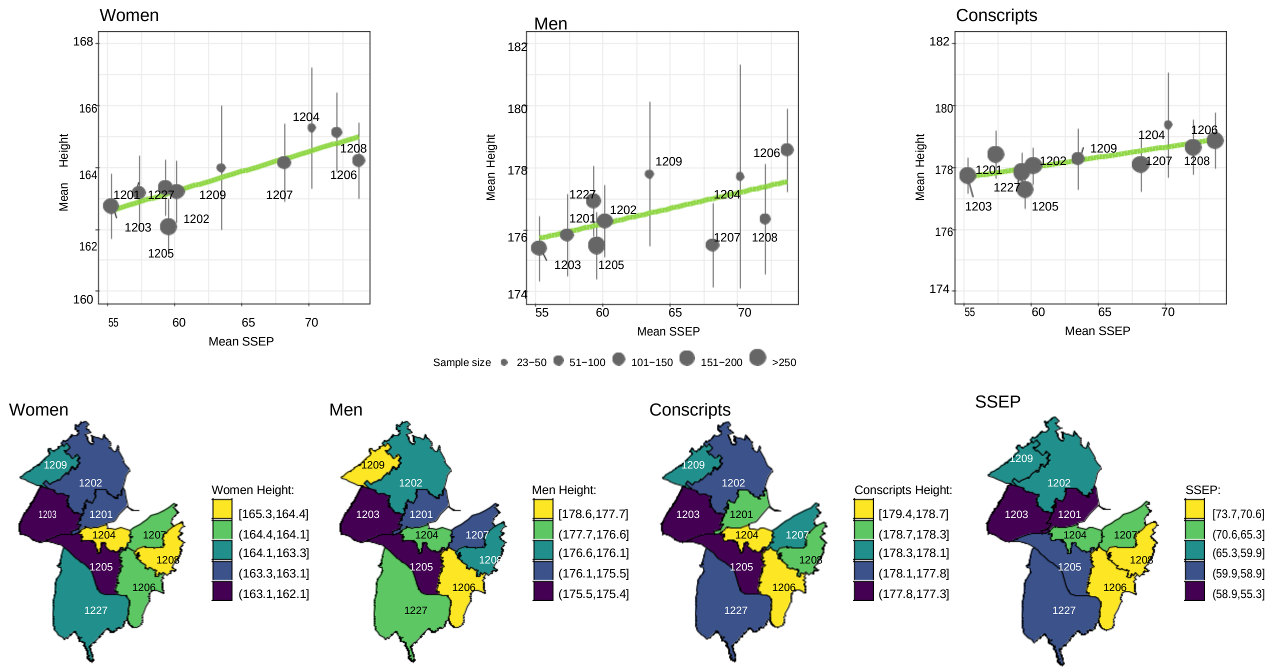
B) Histogram age



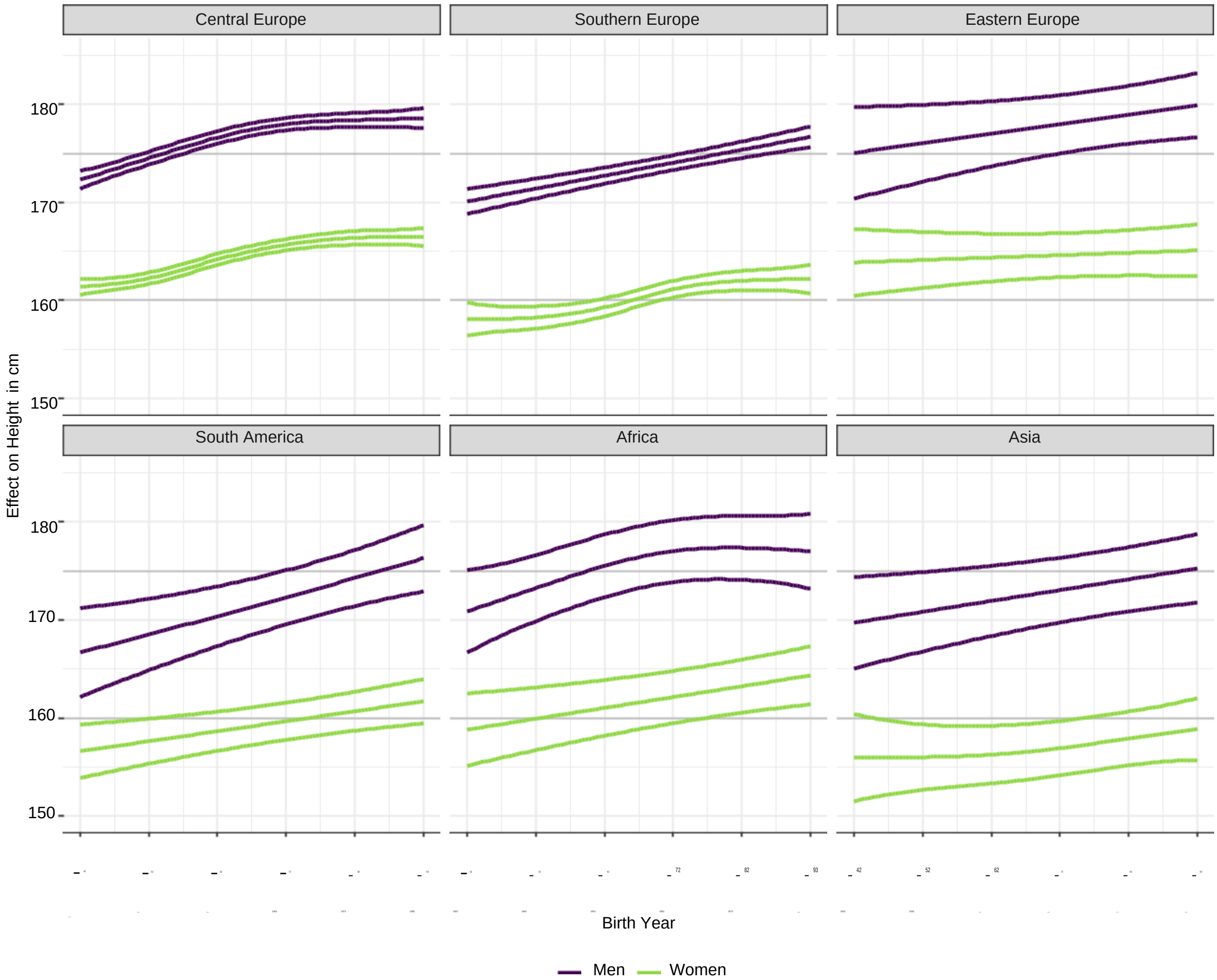
Supplementary Figure S3: Comparison of the adjusted and unadjusted trends shown in Figure 1 (purple and yellow lines, examination years 2005-2017), with unadjusted trends for the examination years 1992-2017 and published averages for young male conscripts (19 years old) from Geneva.



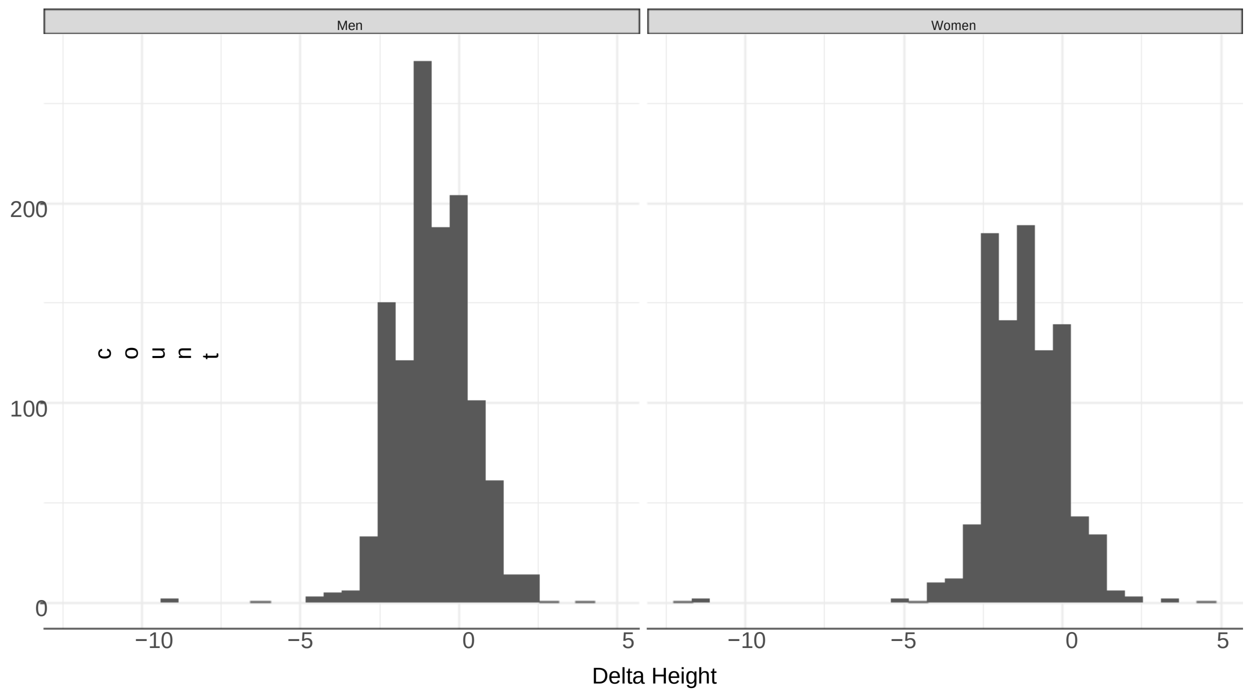
Supplementary Figure S4: Average height of adult male and female *Bus Santé* participants per ZIP code of residence within the city of Geneva (maps on the left side) compared to the average height of conscripts and average area-based Swiss-SEP (SSEP) index for the same areas (maps on the right side). The scatterplots with linear regression lines in the upper row of the graph indicate a positive correlation between average height and Swiss-SEP among ZIP codes.



Supplementary Figure S5: Modelled and adjusted trends for migration background across years of birth among adult men and women in Geneva.



Supplementary Figure S6: Histogram of height loss after age 50 years per year of follow-up in a subsample of *Bus Santé* participants of both sexes.



Reporting checklist for cross sectional study.

Based on the STROBE cross sectional guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the STROBE cross sectionalreporting guidelines, and cite them as:

von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies.

		Reporting Item	Page Number
Title and abstract			
Title	#1a	Indicate the study's design with a commonly used term in the title or the abstract	1
Abstract	#1b	Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background / rationale	#2	Explain the scientific background and rationale for the investigation being reported	3
Objectives	#3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	#4	Present key elements of study design early in the paper	4

Setting	#5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Eligibility criteria	#6a	Give the eligibility criteria, and the sources and methods of selection of participants.	7
	#7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources / measurement	#8	For each variable of interest give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group. Give information separately for for exposed and unexposed groups if applicable.	5
Bias	#9	Describe any efforts to address potential sources of bias	5
Study size	#10	Explain how the study size was arrived at	7
Quantitative variables	#11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	5
Statistical methods	#12a	Describe all statistical methods, including those used to control for confounding	6
Statistical methods	#12b	Describe any methods used to examine subgroups and interactions	6
Statistical methods	#12c	Explain how missing data were addressed	6
Statistical methods	#12d	If applicable, describe analytical methods taking account of sampling strategy	5
Statistical methods	#12e	Describe any sensitivity analyses	7
Results			
Participants	#13a	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed. Give information separately for for exposed and unexposed groups if applicable.	7

Participants	#13b	Give reasons for non-participation at each stage	7
Participants	#13c	Consider use of a flow diagram	7
Descriptive data	#14a	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. Give information separately for exposed and unexposed groups if applicable.	7
Descriptive data	#14b	Indicate number of participants with missing data for each variable of interest	7
Outcome data	#15	Report numbers of outcome events or summary measures. Give information separately for exposed and unexposed groups if applicable.	7
Main results	#16a	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	7
Main results	#16b	Report category boundaries when continuous variables were categorized	7
Main results	#16c	If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	8
Other analyses	#17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	8
Discussion			
Key results	#18	Summarise key results with reference to study objectives	8
Limitations	#19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	9
Interpretation	#20	Give a cautious overall interpretation considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	8
Generalisability	#21	Discuss the generalisability (external validity) of the study results	9

Other Information

Funding	#22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	11

This checklist was completed on 23. November 2021 using https://www.goodreports.org/, a tool made by the EQUATOR Network in collaboration with Penelope.ai